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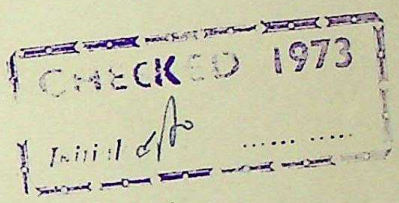
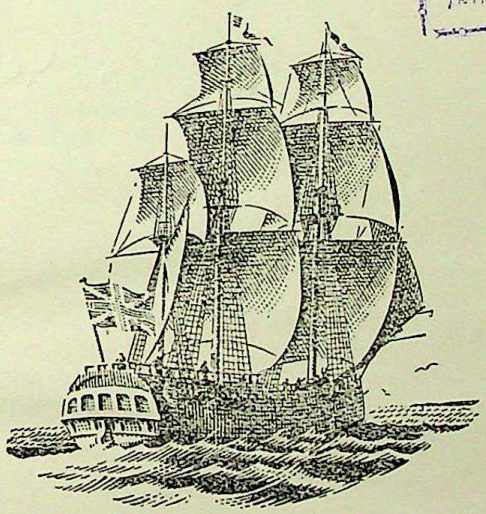
ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind





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A quarterly review designed to record the progress of the sciences in the service of mankind

गुरुकुल कांगड़ी विश्वविद्यालय हरिद्वार

VOLUME III . JANUARY 1944 NUMBER 9

Two chemical anniversaries

There were two fundamental factors in the unparalleled scientific progress of the nineteenth century. One was the formulation of the chemical atomic theory. The other was the establishment of the principle of the conservation of energy. Both were the work of British scientists. The indestructibility of energy was demonstrated by James Prescott Joule. The chemical atomic theory sprang from the genius of John Dalton, the centenary of whose death falls in this present year 1944. From the time of Boyle (1627–91), Britain has produced a succession of great scientists—astronomers, physicists, chemists, biologists, geologists—hardly equalled, and certainly not surpassed, by those of any other country. In this succession were some whose work was not merely great, but epoch-making in the literal sense of the term. Newton, for example, marks the starting-point of modern physics; Darwin's *Origin of Species* was a definite milestone in biology; and J. J. Thomson erected an equally unmistakable frontier sign by his work on the conduction of electricity through gases. It is in such company that Dalton finds his proper setting.

Seldom has the hour more appropriately produced the man. Ten years before Dalton's birth in 1766, Joseph Black had published the first quantitative chemical investigation carried out in accordance with rigid scientific canons. In this work, which dealt with the relationship between the mild and the caustic alkalis, Black had recourse to the balance at every turn, and tacitly assumed both the conservation of matter and the constancy of composition of individual chemical substances. During the succeeding twenty years, the 'age of pneumatic chemistry' was signalled by the discovery of most of the common gases, and by Lavoisier's brilliant elucidation of the composition of the atmosphere. Like Black, Lavoisier appears to have accepted the constant composition of chemical substances as axiomatic, but this view was challenged by his contemporary Berthollet. About 1802, however, Proust settled the question by numerous analyses. Differentiating between a mixture or solution and a chemical compound, he proposed to employ constancy of composition as a touchstone for chemical combination.

Thus new substances, new facts, new methods, and new concepts were to be found in profusion at the opening of the nineteenth century. They called for an informing, integrating generalization: and this was already taking shape in the mind of John Dalton, then an obscure mathematical coach in Manchester.

Born of sturdy yeoman stock, Dalton was characterized even as a schoolboy by his determined reliance upon his own powers. Presented with a difficult problem, he delighted in worrying it out for himself and would decline offers of help from his teacher. 'Yan med deu 't' ('I may do it') was has customary answer, and his confidence was generally well founded. This dogged persistence in mental effort was a happy reinforcement of the profundity of his thought, for he did not think quickly and his contributions to scientific theory were the fruit of prolonged travail. His atomic theory, gradually elaborated during some ten years, was fully published in 1808, in the first part of his *New System of Chemical Philosophy*. Though he was originally led to its formulation by his investigation of the physical properties of gases, he came to perceive that valuable confirmation of its main tenets might be obtained from a study of the relative weights in which elements react together. With the simplest of apparatus, he conducted painstaking experiments on this point, and discovered—as he firmly expected to discover—that each element appeared to consist of particles alike in weight for the same element but varying in weight from element to element.

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This was the talisman which Dalton found to knit together the mass of discrete and disconnected chemical data by then accumulated. Chemistry became a unified science, and to a great extent an exact science. The theory in its original form, like all comprehensive theories, required clarification in some respects and modification or extension in others. Dalton himself failed to appreciate the vital distinction between atoms and those aggregates of atoms later called molecules. That was left to the insight of Avogadro and the common sense of Cannizzaro. But, with the general acceptance of Dalton's theory—particularly when its use was simplified by the addition of Berzelius' system of chemical notation—chemistry was well launched on a flowing tide. Today the Daltonian hypotheses have suffered the fate inevitable to all scientific hypotheses: they have been absorbed in, or replaced by, more accurate descriptions of phenomena—but for a hundred years they charted the chemical ocean.

Nor was it only the ocean of academic chemistry, for the atomic theory was in fact the indispensable basis of the development of the chemical industry, and therefore exerted an influence stretching far beyond the confines of the laboratory. It would be a not uninteresting task to try to evaluate its effect upon the history of the world.

Dalton's epoch is now past; but on looking back we can recognize it as one of the most clearly defined epochs in the whole growth of science. With sure prescience he had seen the point 'towards which the rays of scattered experiments were converging,' and slowly, but with equal sureness, he brought them all to a sharp and illuminating focus.

If tradition is to be trusted—and in this case it is not unduly suspect—the year 1944 will witness another notable anniversary. Exactly 800 years ago, on 11th February, 1144, the English scholar Robert of Chester finished his Latin translation of an Arabic work on alchemy. The translation circulated in Western Europe, and there are grounds for believing it to be the first alchemical text to reach Latin civilization. Though (as Professor Tenney L. Davis pointed out in our last issue) alchemy presupposes the existence of a considerable body of chemical knowledge, development in Europe was from alchemy to chemistry. Hence, if any one day more than any other may be honoured as the birthday of chemistry, it is 11th February, 1144. Whatever the facts, Britain can at least claim that, less than a century after the Norman Conquest, her scholars were seeking out new avenues of learning.

Robert was probably a native of Ketton in Rutland, and owed his cognomen to the fact that he was educated at Chester. Following a widespread custom of the period, he made a lengthy sojourn in Spain in order to assimilate Islamic scholarship. A letter written in 1143 by Peter the Venerable to St Bernard relates that in 1141 Peter came upon Robert and his friend Hermann of Dalmatia—two 'acute and well-trained scholars' residing near the Ebro—and persuaded them to leave their astrological studies for a time and to undertake the translation of the Koran into Latin. This task was completed in 1143; and Robert appears to have returned at once from doctrinal to secular subjects, for the translation of the alchemical text in 1144 was followed in the succeeding year by the first translation of the Algebra of Al-Khwārizmī. The importance of this particular translation would be difficult to overestimate, for it marks the beginning of European algebra.

About 1147, Robert (who had held the office of Archdeacon of Pamplona) returned to England, where he wrote or translated a treatise on the astrolabe, compiled astronomical tables for the longitude of London, 1149–50, and revised for the meridian of London the tables of Al-Khwārizmī previously translated by Adelard of Bath. A minor contribution to mathematics was his use of the word *sinus*, sine, in its trigonometrical sense, as a translation of the Arabic *jaib* (pocket) with the same trigonometrical meaning.

The reign of King Stephen is now so remote as to border on the legendary. It is a pleasant reflection that even in those 'times long gone before' Englishmen were not only advancing the bounds of knowledge but were working in harmony with scholars of a different race and a different creed.

Contributions and correspondence should be sent to the editor: E. J. Holmyard, M.A., M.Sc., D.Litt., F.I.C., Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1. Scientists engaged in research of an interesting or important character are invited to send short notes on work in progress and results obtained.

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Penicillin

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E. CHAIN and H. W. FLOREY

Penicillin, perhaps the most valuable chemotherapeutic agent yet known to science, was a purely British discovery. Yet so prone are British scientists to the national habit of reticence and understatement that in the newspapers credit was not always assigned to the proper quarters. We are happy to be able to publish this authoritative article by Dr Chain and Professor Florey, to whom much of our detailed knowledge of penicillin is due.

The demonstration of the remarkable therapeutic possibilities of the mould product penicillin has led to publicity in the lay press much of which is characterized by a lack of real knowledge of the subject. It may therefore be of interest to trace the development of the use in medicine of this and other substances produced by micro-organisms.

Penicillin is an antibacterial agent produced by a mould. Its formation represents one example of the widespread phenomenon of 'microbial antagonism.' Many species of bacteria and fungi are able, under suitable conditions, to interfere with or prevent the growth of other microbial species. It has now been established that this inhibitory action is in many cases due to the properties of metabolic products formed by the antagonist. The term 'antibiotic' has recently been suggested (Waksman *et al.*, 1942) to designate these substances.

We have to go back more than sixty years for the first suggestion that the phenomenon of microbial antagonism had therapeutic possibilities. Pasteur and Joubert in 1877 described the antagonistic effect of certain contaminating organisms on the growth of the anthrax bacillus. Some of their observations led them to state: 'Tous ces faits autorisent peut-être les plus grandes espérances au point de vue thérapeutique.'

The first serious attempt to employ an antibiotic for curative purposes was that of Emmerich and Loew, who in 1899 utilized the discovery of Bouchard (1889) that *Pseudomonas pyocyanea* was antagonistic to other species of bacteria. They showed that culture medium on which *Ps. pyocyanea* had been growing for a long time had the property of dissolving or killing many pathogenic bacteria. This phenomenon they ascribed to the action of an enzyme 'pyocyanase.' They claimed that experimental anthrax could be cured by pyocyanase and suggested its use for the local treatment of diphtheria and other infections. The clinical efficacy of pyocyanase was questioned by most subsequent observers, but nevertheless it appears to have been on sale in Germany till as late as 1936. Much (1924) suggested the clinical use of antibacterial substances produced by the subtilis-mesentericus group of bacteria.

The production by strains of actinomyces of a substance 'actinomycetin,' capable of dissolving certain pathogenic bacteria, was described by Gratia and Dath (1924). They suggested (1934) that suspensions of bacteria which had been dissolved by actinomycetin could be used for immunizing purposes, and claimed that such 'mycolysates' were more effective than the ordinary vaccines. This technique has not found acceptance in medical practice.

Dubos in 1939 demonstrated the presence of an antibacterial agent in culture filtrates of a soil organism, later recognized as *Bacillus brevis*. This agent was shown to consist of two polypeptides, gramicidin and tyrocidine, which were isolated in the crystalline state. 'Tyrothricin,' the crude mixture of the two polypeptides, has been used locally with some success for the treatment of infected wounds, but it is too toxic for general administration.

THE DISCOVERY OF PENICILLIN

A particularly striking example of microbial antagonism was discovered in 1929 by Professor A. Fleming. A green mould, an accidental air contaminant, grew on an agar plate which he had used for the cultivation of staphylococci. He noticed that in the neighbourhood of the contaminating mould the colonies of staphylococci were dissolving (figure 1). Subcultures of the mould were made in order to study its antagonistic behaviour towards staphylococci and other organisms in greater detail. Fleming showed that the mould, which was subsequently identified as

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Penicillium notatum (figure 2), could be grown on a liquid medium (peptone broth), and that it secreted something into the medium which inhibited the growth of many pathogenic bacteria, even when the broth was diluted as much as 800 times. The susceptible bacteria included pathogenic organisms such as staphylococci and streptococci, which produce some of the most destructive infective lesions in man; other bacteria, such as *Bacterium coli* and *Salmonella typhi*, were not affected (figure 3).

Fleming ascribed the power of the medium to inhibit the growth of bacteria to the presence of an antibacterial agent which he named penicillin. He also noted that broth containing penicillin was not more toxic than ordinary broth when injected into rabbits and mice, and that leucocytes were little affected by it.

Fleming appreciated the possibility that penicillin might be a useful substance to apply as an antiseptic locally to infected wounds, and indeed some cases of indolent septic wounds were so treated. Fleming stated that penicillin 'certainly appeared to be superior to dressings containing potent chemicals' (Fleming, 1932).

The really extraordinary good fortune surrounding Fleming's acute observation of the antibacterial action of his mould contaminant is only now becoming apparent. *P. notatum* is not a very common mould—in fact, contamination of a bacterial culture with it is probably infrequent. In addition, as subsequent work has shown (Waksman, 1941; Wilkins and Harris, 1943), there are many moulds which produce antibacterial substances. Figures 4, 5, 6, and 7 show inhibition of the growth of staphylococci produced by *P. notatum*, *Aspergillus giganteus*, *Penicillium cyclopium*, and *Aspergillus terreus* respectively. The substances produced by the first two moulds have been found to be non-toxic, while those from the last two are very toxic. This emphasizes the point that only after extraction of the active substance, and sometimes after considerable purification, can its therapeutic possibilities be ascertained.

Following Fleming's work, Clutterbuck, Lovell, and Raistrick (1932) endeavoured to isolate penicillin. They showed that penicillin was formed when the mould was grown on a synthetic culture medium, and this, they thought, would facilitate its isolation. They concluded that it was a very labile substance, and as the extraordinary properties of penicillin were not realized at the time, the work was not pursued. They found that concentrations of culture medium at 40° C *in vacuo* inactivated penicillin; that it could be extracted from the culture medium with ether after acidification; and that the greater part of its activity was lost on evaporation of the ether solution in a stream of air.

Little further interest seems to have been taken in the isolation of penicillin and its possible application to medicine, though Reid (1935) reported a few experiments which tended to show the labile nature of the active substance.

Though discovery of the chemotherapeutic effects of penicillin has overshadowed its use in bacteriology, Fleming (1932) found that it is a very useful ingredient of culture media, suppressing the growth of sensitive organisms while permitting the growth of insensitive species. In this way it is possible, for example, easily to separate the influenza bacillus of Pfeiffer from accompanying organisms such as the streptococcus. Fleming has used this differential medium for various purposes ever since his original observations, the crude penicillin-containing culture medium being adequate for bacteriological purposes (Fleming, 1929, 1932; Fleming and Maclean, 1930).

THE DISCOVERY OF THE CHEMOTHERAPEUTIC PROPERTIES OF PENICILLIN

Through an interest in the problem of natural immunity, one of us (Goldsworthy and Florey, 1930) began to study the properties and physiological significance of a powerful natural antibacterial agent, lysozyme. This substance, discovered by Fleming, is widely distributed in nature, occurring in egg-white, bacteria and plants, and many animal tissues. The work on lysozyme was pursued until it was finally purified (Roberts, 1937), and its nature and mode of action as a carbohydrate-splitting enzyme were established (Meyer *et al.*, 1936; Epstein and Chain, 1940). In 1938, during the course of this work, the writers of the present article concluded that it might be profitable to conduct a systematic investigation into the chemical and biological properties of antibacterial substances produced by micro-organisms. Though the existence of such substances had been clearly established in many cases, very little was known at that time about their chemical and biological properties, and it was hoped that a systematic study might lead to the preparation of new compounds of biological interest. By great good fortune one of the first to be investigated was penicillin, which, despite the unfavourable account in the literature

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of its chemical properties and interesting biological characteristics. It seemed important to obtain detailed information about the chemical nature of a substance which inhibited the growth of many pathogenic bacteria, apparently in high dilutions. That this substance prevented the growth of staphylococci appeared particularly important, as no substance was known that effectively controlled staphylococcal infection. In view of the statements of Fleming, and of Clutterbuck, Lovell, and Raistrick, that neutralized sterile culture filtrates containing penicillin might retain their antibacterial activity unchanged for many weeks, it appeared likely that conditions might be found in which the active substance could be isolated and purified.

The first problem presenting itself in the attempt to isolate penicillin was to find a simple and quick quantitative test for the substance. The serial dilution method normally used in bacteriological work was considered too complicated for frequent assays, as it required the absolute sterility of each sample to be tested. A suitable assay method was devised by Dr N. G. Heatley. It may be of interest to describe his method, as it has proved invaluable not only for the work on penicillin but also for similar investigations on other antibacterial products (figure 9).

An agar plate is seeded with the test organism—*Staphylococcus aureus* has been used as a routine—by pouring on a broth culture of the organism, draining off the excess, and drying the plate for 1–2 hours in the 37° C incubator with the lid raised. Short open-ended cylinders of glass or vitreous porcelain are then placed on the surface of the agar, and the solutions to be assayed are placed in the cylinders. After incubation, the surface of the agar becomes covered with a continuous film of bacterial growth except for a circular zone around each cylinder where the penicillin has diffused out and inhibited growth. The diameter of this zone is related to the concentration of penicillin in the solution in the cylinder, and by setting up solutions containing known amounts of penicillin a curve relating the two can be drawn. The actual diameter of the zone produced by any given solution varies slightly from day to day, since it depends on a number of factors, some of which are difficult to control in practice; but the variation can be countered by including one or more solutions of known strength in each assay.

For the same reasons which apply in the case of other biologically active agents of unknown chemical and biological characteristics, it was found convenient to express the antibacterial activity of penicillin in terms of some standard preparation of penicillin. The 'unit' originally taken for convenience in this laboratory only has since been adopted as the 'Oxford unit' by some other workers. It was defined originally as that amount of penicillin contained in 1 ml. of a certain purely arbitrary stock solution. The latter was exhausted long ago, but other primary standards, in the form of dry preparations, were standardized against it. Until penicillin is obtained in a clearly characterizable form the only way in which the potency of a given solid or liquid preparation can be measured in terms of Oxford units is by a direct comparative assay against a preparation containing a known number of these units. A rough indication of the size of the unit may be gathered from the following facts:

(1) Pure penicillin contains about 1,000 units per milligram.
(2) Most strains of staphylococci are usually inhibited by a concentration of 0·01 to 0·05 units per millilitre.

Using Heatley's test method, it was quickly established that penicillin was an acid of low molecular weight, soluble and stable in various organic solvents, but stable in water only between *p*H 5 and 7. It was found possible—in confirmation of the results of Clutterbuck, Lovell, and Raistrick—to extract penicillin into ether at an acid *p*H; from the ether solution penicillin could be re-extracted into water in the form of its salts by adjusting the *p*H to neutrality. During these operations no loss of antibacterial activity occurred as long as the solutions were kept cold. These observations have formed an integral part of every extraction method since used. Chloroform and amyl acetate are used now for the extraction and purification of penicillin on a large scale.

On evaporation of the watery solution *in vacuo* from the frozen state, a dry penicillin salt preparation was obtained which retained its activity for long periods. The first crude preparations made by extracting penicillin from the culture medium into ether and back into water contained, as we now know, only about 1 per cent. of pure penicillin. However, even these very crude preparations inhibited the growth of staphylococci and other bacteria at a dilution of 1 part in 500,000. This antibacterial effect was of the same order of magnitude as that of many powerful antiseptics, e.g. acriflavin. Not realizing what an extraordinarily powerful antibacterial substance penicillin was, we thought it had been obtained

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in a relatively highly purified form and went on to test the toxicity of this crude preparation. Intravenous injection into mice showed that it possessed a low toxicity—20 gm. mice survived an injection of 10 mgm. with little or no toxic effect. It was also seen that penicillin appeared very rapidly in the urine of the injected animals. After these encouraging findings it was decided to carry out a small-scale therapeutic experiment on eight mice infected with haemolytic streptococci. Four of these animals were treated with repeated injections of the crude penicillin salt preparation and four served as a control. One of the treated animals survived indefinitely, while the three others died many days later than the untreated ones, which succumbed within 24 hours. This experiment was sufficiently encouraging to make it seem probable that penicillin had chemotherapeutic potentialities, and it became apparent that results would be obtained most quickly by the co-operative effort of a team of workers. The most urgent immediate problems to be tackled were: (1) to produce larger quantities of penicillin, which, it was found, was produced by the mould only in very small amounts; (2) to make a thorough study of the biological properties of penicillin; (3) to purify penicillin as much as possible and to study its chemical nature.

We were particularly fortunate in our collaborators. Dr N. G. Heatley not only devised the rapid and simple assay method described above which made it possible to carry out all subsequent work expeditiously, but designed and constructed the first large-scale laboratory plant for growing the mould and extracting penicillin. Dr A. G. Sanders later devised and built alternative apparatus for the extraction of penicillin on a larger scale. Professor A. D. Gardner collaborated throughout on the bacteriological aspects of the work and Dr M. A. Jennings on the biological investigations. Later Dr E. P. Abraham joined us for the chemical investigations. When the stage of therapeutic trials on man was reached, Dr C. M. Fletcher and, later, Dr M. E. Florey were responsible for the clinical observations, with the help of many physicians and surgeons.

The large-scale preparation of penicillin was carried out in Oxford by Mr G. Glister and his assistants and Mr J. Kent. In the purification of the penicillin the skilful technical assistance of Mr D. Callow has been invaluable. In the later stages of the work Mr Callow has had the help of Mr J. B. Burtt.

For the preparation of larger amounts of penicillin special culture vessels were used, each containing about 1 litre of culture medium. The synthetic medium described by Clutterbuck, Lovell, and Raistrick was employed, with yeast extract added to accelerate the growth of the mould. Considerable difficulties were encountered in the first attempts to grow the mould on a larger scale. The main difficulty was soon traced to the fact that contamination by atmospheric bacteria occurred more frequently when working with large culture vessels. Certain of these air bacteria produced an enzyme destroying penicillin (Abraham and Chain, 1940), so that when they were present as contaminants in the medium any penicillin produced by the mould was promptly destroyed. This observation was of the greatest importance and explains why it has been so difficult to produce penicillin on a large scale. Large-scale aseptic procedures need meticulous care, and much of the development work of commercial firms has been devoted to overcoming contamination by the ubiquitous air organisms.

The crude penicillin preparation proved to be fairly stable. When larger amounts became available, attempts were made to obtain penicillin in the pure state (Abraham and Chain, 1942). As is now known, the crude penicillin salt preparations are mixtures of very many different substances. The isolation of penicillin from this mixture was no easy problem because of its instability towards many chemical reagents and the unfavourable solubilities of the free acid and its salts. It was found not only that penicillin was destroyed by acid and alkali but that it was inactivated by many metal ions, in particular by zinc, cadmium, copper, and mercury. The alkali and alkaline earth salts were stable but extremely soluble in water; no organic cation forming a relatively insoluble salt with penicillin suitable for purification purposes was found. Penicillin was also destroyed by primary alcohols, primary amines, ketonic reagents and oxidizing agents; it was, however, found to be stable towards reduction with various reducing reagents.

The methods which could be used for the purification of penicillin were therefore limited to distribution between different solvents and to adsorption methods. Extensive and successful use has been made of chromatography. By a suitable combination of distribution between solvents, various methods of chromatography, and a reduction process by aluminium amalgam (which does not affect penicillin but changes the solubilities and chromatographic behaviour of impurities) it

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has been possible to obtain barium salts possessing an activity of about 1,000 Oxford units per milligram. Recently, crystalline preparations of salts of penicillin have been obtained, so that the limit of purification seems to have been reached.

Work on the constitution of penicillin has been carried out in Oxford in the Sir William Dunn School of Pathology by Dr E. P. Abraham and one of us (E.C.), and since 1942 in collaboration with Dr Wilson Baker and Sir Robert Robinson in the Dyson Perrins Laboratory. Subsequently many other workers both in England and America joined in the attack on various aspects of the problem, and especially in relation to production and purification. We can speak only in general terms of the chemical work in Oxford which has led to the elucidation of the constitution of the breakdown products of penicillin and opened the way to eventual synthesis. Before the publication of technical details was prohibited a few brief progress notes appeared in *Nature*. These were of a preliminary character and retain little more than historical value. A characteristic breakdown product of penicillin, penicillamine, has been described (Abraham, Baker, Chain, and Robinson, 1943). This substance, an amino-acid, is obtained by acid hydrolysis of penicillin. Another breakdown product, penillic acid, has been found by Duffin and Smith (1943). This substance is formed on acid inactivation of penicillin.

The purest preparations of penicillin inhibited the growth of staphylococci at the astonishing dilution of 1 part in 50 millions; a strong partial inhibition was obtained in a dilution of 1 part in 150 millions. Gonococci and meningococci were about twice as sensitive as staphylococci. Table I illustrates the relative activity of penicillin against a wide range of bacteria. The results recorded agreed with those originally found by Fleming on crude penicillin-containing culture medium, with the addition of the important group of gas gangrene organisms among the sensitive and the tubercle bacillus among the insensitive species. It is noteworthy that *Actinomyces bovis* was sensitive. The figures in this table are of comparative value only, as they were derived from experiments with crude penicillin. (A typical 'dilution test' is shown in figure 8.)

The extraordinary potency of the antibacterial action of penicillin would not by itself make this substance unique, for Waksman and Woodruff (1941) have isolated an antibacterial agent, actinomycin A, from culture filtrates of an actinomyces, which is almost equally potent. But whereas actinomycin A is extremely toxic to animals, penicillin has little if any toxic effect, even when administered in large doses. Mice weighing 20 gm. tolerated the intravenous injection of 20 mg. of a penicillin preparation containing 325 units per milligram without any noticeable ill effect, while Hobby *et al.* (1942) found the lethal dose for 18 gm. mice to be about 30 mg. of 250 units per milligram sodium salt. This lack of toxicity applies also to much less pure preparations. That none of the impurities is very toxic is an astonishing and particularly fortunate circumstance, for it has made possible the clinical use of penicillin in a crude form without subjecting it to a complicated purification process. Penicillin preparations containing about 100 units per milligram are commonly employed for clinical purposes of all kinds, but most of the early pharmacological and biological studies were carried out with less pure preparations, containing about 40 units per milligram.

After it had been shown that large amounts were harmless when given intravenously, the lack of toxicity to important individual cell types was demonstrated *in vitro*. For example, suspensions of leucocytes tolerated a 1 in 1,000 solution of material of 40 units (which inhibited the growth of staphylococci at a dilution of 1 in 1 million) and later were found to tolerate a 1 per cent. solution of material of 250 units per milligram (which inhibited the growth of staphylococci at 1 in 25 millions). The significance of this fact will be appreciated when it is realized that the body deals largely with infecting organisms by means of the leucocytes—mobile allies which ingest and kill the bacteria. These experiments demonstrated further the important point that with increasing purification toxicity was reduced. Another demonstration of the non-toxicity of penicillin preparations (in this case containing about 40 units per milligram) was furnished by tissue culture studies, undertaken by Dr P. Medawar and Dr F. Jacobi. Fibroblasts, epithelial cells, and monocytes were capable of growth after they had been immersed for 48 hours in a 1 in 2,000 solution. In a number of pharmacological experiments it was established that penicillin had no effect on the blood-pressure, heart-beat, or respiration of cats when given in doses sufficient to produce an antibacterial concentration in the blood. It could be injected directly into the brain and cerebrospinal fluid of rabbits without toxic symptoms.

An important question was whether penicillin was destroyed in the body or by the tissue

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TABLE 1

DILUTIONS OF PENICILLIN AT WHICH VARIOUS INHIBITORY EFFECTS HAVE BEEN OBSERVED

(From Abraham *et al.*, 1941)

Bacterial species	No. of strains	Dilutions at which inhibitory effects were observed			Notes
		Complete	Partial	None	
N. gonorrhoeae[1]	6	2,000,000	>2,000,000	>2,000,000	—
N. meningitidis	1	1,000,000	2,000,000	4,000,000	—
Staph. aureus	4	1,000,000	2,000,000	4,000,000	—
Strep. pyogenes	3	1,000,000	2,000,000	4,000,000	—
B. anthracis	1	1,000,000	2,000,000	4,000,000	—
A. bovis (hominis)	1	1,000,000	2,000,000	4,000,000	Deep glucose-agar shake cultures.
Cl. tetani[2]	1	1,000,000	—	—	Limit not observed.
Cl. welchii	1	1,500,000	—	—	Limit not observed.
Cl. septique	1	300,000	1,500,000	7,500,000	Fivefold dilutions used.
Cl. oedematiens	1	300,000	—	1,500,000	Inoculum of spores.
Strep. viridans[3]	2	625,000	—	3,125,000	But see other strains below.
Pneumococcus[3]	6	250,000	500,000	1,000,000	3 of type 1; one each of types 3, 7, and 9. Some complete at 500,000.
C. diphtheriae (mitis)	1	125,000	—	625,000	Intermediate dilutions not tested.
C. diphtheriae (gravis)	1	32,000	64,000	128,000	—
S. gärtneri	1	20,000	40,000	80,000	—
S. typhi	2	10,000	30,000	90,000	Higher of two results shown.
Pneumococcus[3]	3	9,000	—	27,000	Types 1, 7, and 19.
Anaerobic streptococcus[3]	1	4,000	8,000	16,000	—
Proteus	3	4,000	32,000	60,000	Best strain shown. Others 4 times less sensitive.
Strep. viridans[3]	1	4,000	8,000	16,000	—
Past. pestis	2	1,000	100,000	500,000	Partial inhibition between 1,000 and 100,000
S. typhimurium	1	< 1,000	8,000	16,000	Partial 1,000–8,000.
S. paratyphi B	2	< 1,000	5,000	10,000	Partial 1,000–5,000.
Bact. dysenteriae Shiga	1	2,000	4,000	8,000	—
Br. abortus	1	2,000	4,000	8,000	—
Br. melitensis	1	< 1,000	2,500	10,000	—
Anaerobic streptococcus	1	< 4,000	< 4,000	4,000	—
V. cholerae	1	< 1,000	1,000	2,000	—
Bact. coli	5	< 1,000	< 1,000	1,000	One strain showed complete 200, none 400.
B. friedländeri	1	< 1,000	< 1,000	1,000	—
Ps. pyocyanea	2	< 1,000	< 1,000	1,000	—
Myco. tuberculosis	1	< 1,000	< 1,000	1,000	See text.
L. icterohaemorrhagiae	1	< 3,600	< 3,600	3,600	Lower dilutions not tested.

[1]Another strain was inhibited only up to 32,000. [2]Grown in Lemco broth. In beef broth complete inhibition only reached 100,000. [3]In *Pneumococcus*, *Strep. viridans*, and anaërobic streptococci, different strains appear at different levels in the table. [*A.* = *Actinomyces*; *Br.* = *Brucella*; *C.* = *Coryne bacterium*; *Cl.* = *Clostridium*; *L.* = *Leptospira*; *Myco.* = *Mycobacterium*; *N.* = *Neisseria*; *Past.* = *Pasteurella*; *Ps.* = *Pseudomonas*; *S.* = *Salmonella*; *V.* = *Vibrio*.]

constituents. It was found that the antibacterial activity was in no way diminished by blood, pus, tissue autolysates, or protein hydrolysates. Penicillin was to a large extent excreted rapidly by the kidneys, which indicated that relatively little destruction had occurred in the body.

The antibacterial activity of penicillin within wide limits was not influenced by the number of bacteria present. This fact and its insensitivity to the products of tissue decomposition give penicillin important advantages over the sulphonamide drugs, which do not act effectively in the presence of protein breakdown products or if large numbers of bacteria are present.

Penicillin even in strong solutions does not kill bacteria immediately, but merely inhibits their

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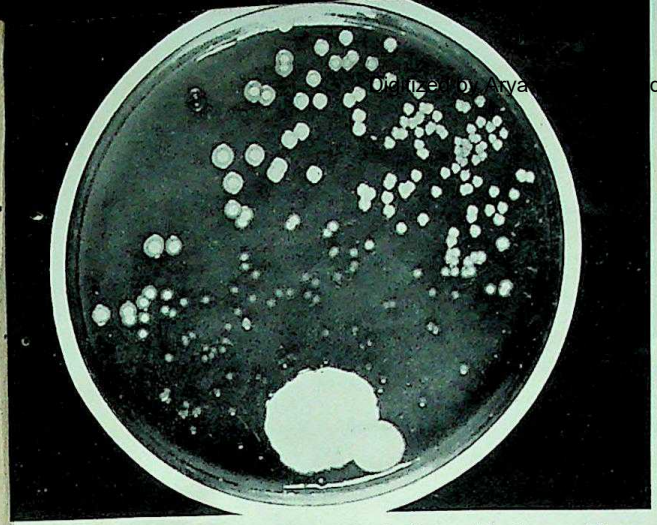

FIGURE 1 – *This is Fleming's original plate with the mould contaminant. From descendants of this mould all the penicillin in the world was made until recently. Note how colonies of staphylococci are disappearing in the neighbourhood of the mould.*

FIGURE 2 – *Colonies of* Penicillium notatum *growing on n* (*Enlarged* 1½ *times.*)

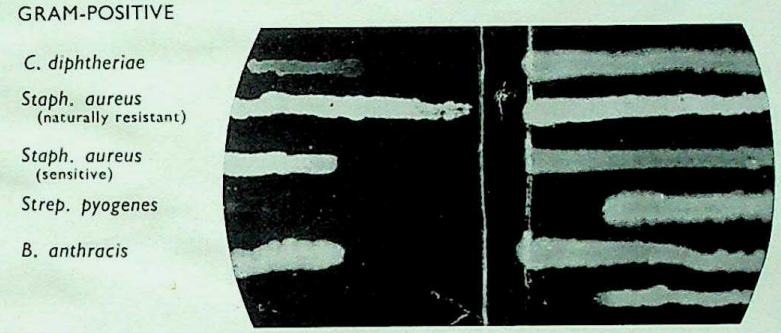

FIGURE 3 – *A 'gutter plate' prepared by Fleming's method. A gutter is cut in a nutrient agar plate and the gutter then filled with melted agar containing penicillin. The penicillin diffuses from this strip a certain distance into the rest of the agar. Various species of bacteria are planted on the agar in streaks. Those which are not sensitive to penicillin grow right up to the gutter. Those which are sensitive are prevented from growing where the penicillin has diffused and so do not grow right up to the gutter.*

GURE 4 – *A culture of* Penicillium notatum *entre) on nutrient agar. After a few days' growth e agar plate was heavily seeded with staphylocci. There is a clear zone around the mould here the staphylococci have not grown.*

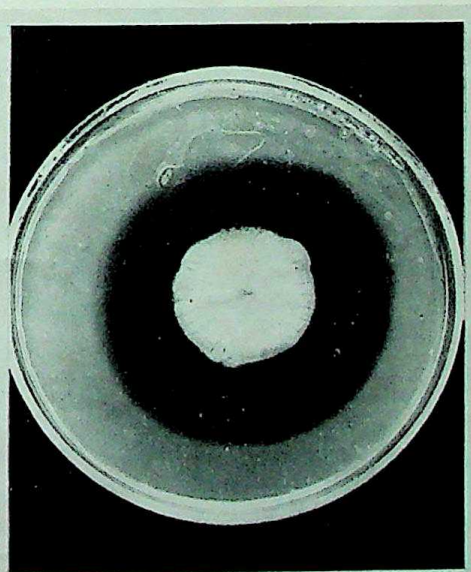

FIGURE 5 – *A culture of* Aspergillus giganteus *treated in a similar way to figure* 4. *This mould produces a penicillin-like substance.*

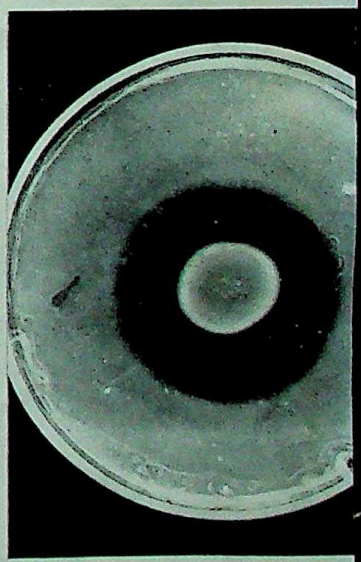

FIGURE 6 – *A culture of* Penicilliu ium *treated in a similar way to fig mould produces penicillic acid (not re way to penicillin), which is toxic.*

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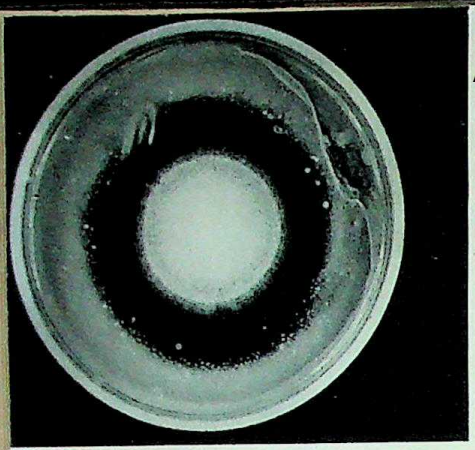
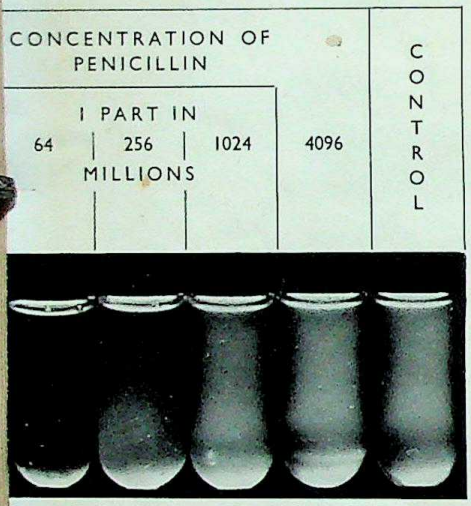
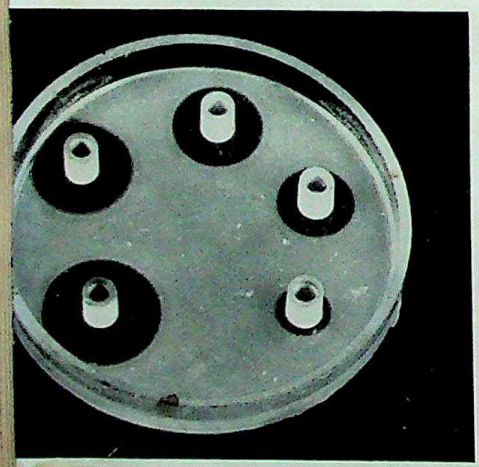


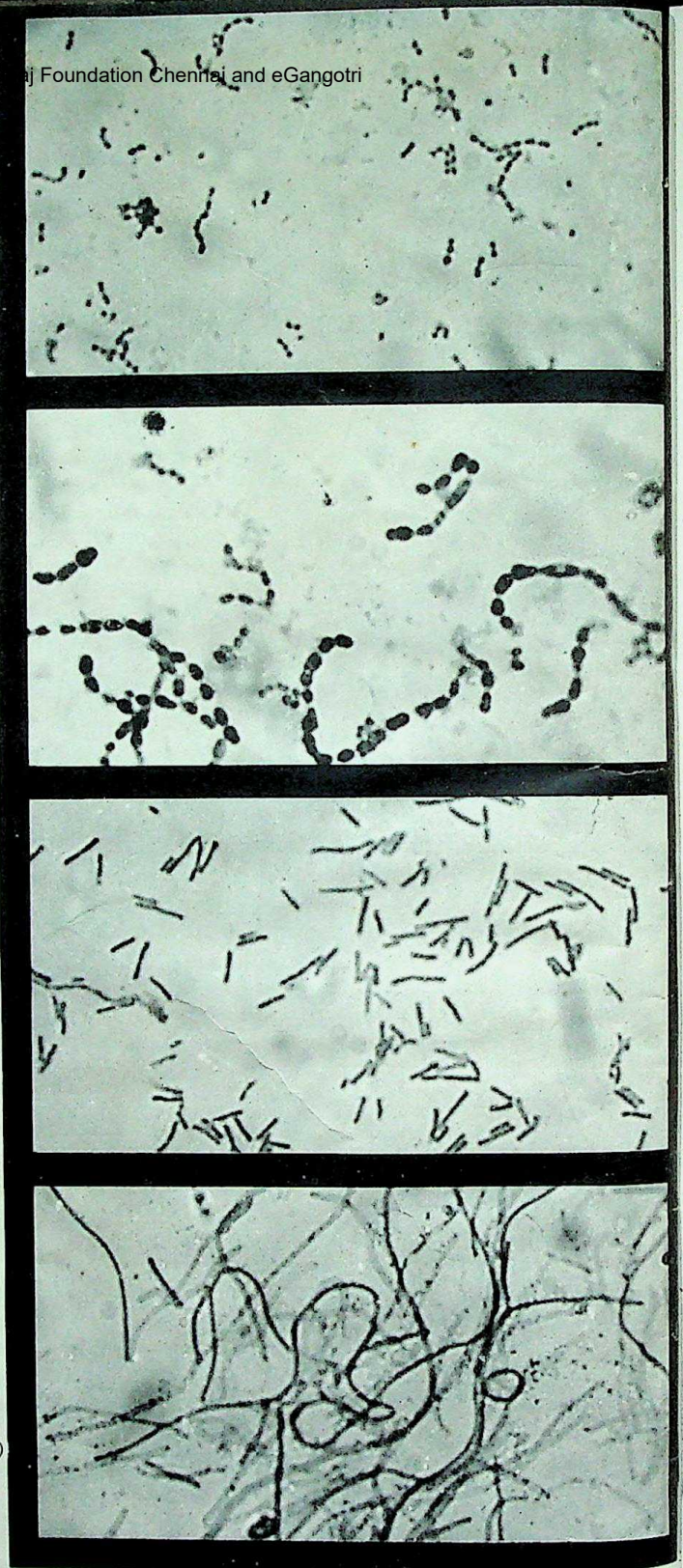
7 – A culture of Aspergillus terreus *treated in way to figure 4. This mould produces terreic h is toxic.*



8 – Serial dilutions of penicillin in broth con- staphylococci. Growth of the bacteria in the tubes has been suppressed by penicillin. This method ed for assay purposes.



9 – Heatley's assay method. Cylinders of porcelain on the surface of an agar culture medium which avily sown with staphylococci. Penicillin solutions in the cylinders and diffuse into the agar, causing an of bacterial growth. The size of the circular zone on bears a relationship to the amount of penicillin



(*a*)

(*b*)

(*c*)

(*d*)

FIGURE 10 – *Morphological changes exhibited by bacteria grown in a strength of penicillin not sufficient to stop all growth. Giant forms are produced, as can readily be seen from comparison with the untreated bacteria.*

(*a*) *Normal streptococci.* (×1,000.)
(*b*) *Penicillin-treated streptococci.* (*Same magnification.*)
(*c*) *Normal typhoid bacilli.* (×1,000)
(*d*) *Penicillin-treated typhoid bacilli.* (*Same magnification.*)

(We are indebted to Dr M. A. Jennings for the preparations, and to Dr A. G. Sanders and Mr H. A. for the photographs.)

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growth. This was established by demonstrating that the respiration of staphylococci remained unaffected by a strong solution over many hours, as well as by the usual bacteriological methods. One may conceive that the main action of penicillin against bacteria in the animal body is to inhibit multiplication of the organisms. This has an important corollary in clinical application, in that measures must be taken to keep penicillin in contact with the organisms for a sufficient length of time to enable the leucocytes to do their work. Precisely how penicillin interferes with bacterial division has not yet been determined. An interesting phenomenon (Gardner, 1940) associated with the inhibition of bacterial growth was the production of giant forms when susceptible bacteria were grown in a concentration of the drug just insufficient to suppress growth completely. A similar phenomenon was shown by relatively insensitive bacteria, such as the typhoid organism. This is a morphological demonstration of the interference of penicillin with the division mechanism of bacteria (figure 10).

Penicillin was readily absorbed after intramuscular or subcutaneous injection, but not after oral administration, since it was destroyed by the hydrochloric acid of gastric juice. It was, however, absorbed from the small intestine, though not from the colon where, apparently, the bacteria destroyed it. It was excreted into the saliva and bile, but did not pass freely from the blood-stream into the cerebrospinal fluid.

With the establishment of all the above-described biological properties it seemed highly likely that

TABLE II

RESULTS OF THERAPEUTIC TESTS ON MICE INFECTED WITH *Strep. pyogenes, Staph. aureus and Cl. septique*
(From Chain *et al.*, 1940)

Expt.	—	Dose of infecting culture (ml.)	Interval before starting treatment (hrs.)	Duration of treatment	Single dose (mg.)	Total dose (mg.)	No. of mice	Survivors at end of										
								hours			days							
								6	12	24	2	3	4	5	6	7	8	9	10
Strep. pyogenes—Lancefield, Gp. A.																			
1	Controls	0·5	—	—	—	—	25	—	15	9	8	6	—	5	—	4	—	—	4[1]
	Treated	0·5	1	12 hrs.	2	10·0	50	—	—	—	49	42	—	34	30	28	—	26	25
2	Controls	0·5[2]	—	—	—	—	25	24	3	0[3]	—	—	—	—	—	—	—	—	0
	Treated	0·5	2	45 hrs.	0·5	7·5	25	24	—	—	—	—	—	—	—	—	—	—	24
Staph. aureus[4]																			
1	Controls	1·0	—	—	—	—	24	21	1	0[3]	—	—	—	—	—	—	—	—	0
	Treated	1·0	1	55 hrs.	0·5	9·0	25	25	12	—	11	—	10	—	—	—	—	—	8
2	Controls	0·2[2]	—	—	—	—	24	23	15	5	0	—	—	—	—	—	—	—	0
	Treated	0·2	1	4 days	0·5	11·5	24	—	23	22	—	—	21	—	—	—	—	—	21
Cl. septique																			
1	Controls	See text	—	—	—	—	25	—	21	0[5]	—	—	—	—	—	—	—	—	0
	Treated	—	1	10 days	0·5	19	25	—	—	24	21	—	18	—	—	—	—	—	18
		—	1	10 days	1·0	38	25	—	—	—	—	—	24	—	—	—	—	—	24

[1] A control mouse which was killed by mistake at 24 hours is counted as a survivor. Heart-blood culture strongly positive.
[2] Between experiments 1 and 2 the virulence of the organism was raised by passage. [3] Controls all dead within 16 hours.
[4] A bovine strain exceptionally virulent to mice kindly supplied by Dr H. J. Parish of the Wellcome Laboratories.
[5] Controls all dead within 17 hours.

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penicillin in proper dosage would prove to have outstanding chemotherapeutic properties *in vivo* against susceptible organisms. That this was indeed the case was shown in a series of mouse protection experiments, the results of which are set out in Table II.

These animal experiments demonstrated clearly that penicillin was not only an 'antiseptic,' as Fleming had suggested, but a chemotherapeutic agent likely to be of first importance. The final assessment of its value to medicine depended, however, on whether it could be used for the successful treatment of naturally occurring disease in man.

All work with penicillin has been constantly hampered by the difficulty of procuring enough material, and the step from mouse to man was a large one. Eventually, in the course of some months, enough material was accumulated for a trial on man.

The first injection given was 100 mgm. intravenously of the same material that had been used for the mouse protection experiments (containing about 10 units per milligram). A little over an hour later the patient had a shivering attack and a rise of temperature. Repetitions of the injection gave similar results, so that it was clear that crude penicillin contained some pyrogenic material. It was found that this pyrogenic material could be removed by chromatographic separation. Although the amount of penicillin required for the first two cases with severe infection was underestimated, good indications were obtained of benefit in an infection caused in one case by the staphylococcus and in the other by the streptococcus. Four more cases, two with severe sepsis, were treated with such encouraging results that it became imperative to procure larger quantities of penicillin (Abraham *et al.*, 1941).

Now that most of the difficulties have been overcome it is interesting to look back at that time when most people considered the use of penicillin in therapy impracticable because of its supposed lability, and because of the large volume of culture medium and great labour involved in its preparation. Nevertheless the work was pressed on, and with material partly made in Oxford and partly produced by Imperial Chemical Industries it was possible to treat fifteen cases of severe sepsis, most of them patients who had had every appropriate form of therapy before penicillin was used (Florey and Florey, 1943). During this clinical trial an effective dosage and method of use were worked out, and it is of interest that from a large series of cases recently treated in America the dosage and form of treatment adopted are practically the same as those originally proposed (Keefer *et al.*, 1943).

Penicillin appears to be a drug with which a striking therapeutic effect can be produced with quantities far below any toxic level. In most cases with new drugs the upper limit is determined by the occurrence of toxic symptoms. For example, in judging the correct dosage of the sulphonamides the aim has been to give as much as possible short of producing a toxic effect. With penicillin the aim has been to give as little as possible owing to the great rarity of the product. There can be little doubt that if penicillin becomes cheap and abundant the doses now given will be considered small, though they are in most cases effective. In treating severe generalized sepsis caused by such organisms as the staphylococcus and streptococcus, penicillin has to be applied to the lesion via the blood-stream, so the drug is administered either by intravenous or by intramuscular injection; but for many septic lesions it is possible to apply solutions or other preparations locally to the infected region, thus effecting a great economy. Methods and dosage for this form of application have been devised (Florey and Florey, 1943; Clark *et al.*, 1943; Bodenham, 1943; Florey, M. E., and Williams, 1944). Local application has been shown in some hundreds of cases to be effective in ridding lesions of susceptible pathogenic organisms, with great consequent benefit to the healing and restoration of function of the infected part. The importance of these observations for the treatment of war wounds, the majority of which are more or less septic, need hardly be stressed.

There is reason to believe that not every infection, even by such an organism as the staphylococcus, may be controllable. It has been found (Abraham *et al.*, 1941) that it is possible to habituate organisms to grow in penicillin. In this way they become penicillin-resistant just as certain streptococci become sulphonamide-resistant and hence not amenable to therapy. This production of penicillin-resistant strains has recently been confirmed (Rammelkamp and Maxon, 1942; McKee and Houck, 1943). Further, a certain number of strains of *Staph. aureus* are naturally resistant. Scott Thomson (1943) has recently shown that these constitute about 4 per cent. of the staphylococci occurring in war wounds. On the other hand, strains of organisms which have become sulphonamide-resistant remain penicillin-sensitive.

The remarkable chemotherapeutic effects which

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can be obtained with penicillin, and local infections have now been amply confirmed by American workers (Herrell, 1943; Keefer *et al.*, 1943), and the position may be stated in this way: if an organism is highly sensitive *in vitro* to the action of penicillin, then a curative effect can be obtained *in vivo* if a suitable dose is administered by a proper technique for a sufficient length of time. One possible exception to this is where the heart-valves are infected.

The potentialities of penicillin are great, and one can only wonder at the succession of fortunate happenings attending its discovery and development. Intensive research in the field of antibiotics carried out mostly during the last few years has disclosed none which is not too toxic for general administration. Thus it becomes more and more apparent that penicillin occupies at present a unique position among antibiotics in combining great antibacterial power with very low toxicity. Table III is a selection of antibiotics so far discovered and described.

The only antibiotic, other than penicillin, so far examined which merits attention as a chemotherapeutic agent is helvolic acid. This substance has many desirable properties, such as stability, low toxicity to leucocytes and tissue cultures, and relatively low toxicity following a single intravenous injection, but its prolonged administration results in severe liver damage. Strains of staphylococci naturally resistant to penicillin are quite sensitive to helvolic acid.

It is proper that new and potent drugs should be used at first mainly on late and desperate cases, and such has, in the main, occurred with penicillin used parenterally. Now that its therapeutic effect and lack of toxicity are generally recognized, there should be no difficulty in using the material at the earliest possible moment or, better still, in employing it prophylactically. The only barrier standing in the way of widespread application is the scarcity of the material. Great efforts are being made by commercial firms and others, both in this country and in America, to bring production to a maximum by increasing the yields obtained from culture and by improving extraction methods. Even though large amounts may eventually be produced by this means, it would appear likely that the best prospect of supplying the great need will lie in the synthesis of the active

TABLE III

Antibiotic	*Source*	*Author*	*Organisms affected*
Gramicidin	*Bacillus brevis*	Dubos, 1939	Predominantly Gram-positive
Actinomycetin	*Actinomyces albus*	Gratia and Dath, 1924	Gram-positive and Gram-negative
Actinomycin A and B	*Actinomyces antibioticus*	Waksman and Woodruff, 1941	Predominantly Gram-positive
Proactinomycin	*Proactinomyces Gardner*	Gardner and Chain, 1942	Predominantly Gram-positive
Streptothricin	*Actinomyces lavendulae*	Waksman and Woodruff, 1942	Gram-positive and Gram-negative
Gliotoxin	*Trichoderma lignorum*	Weindling and Emerson, 1936	Gram-positive and Gram-negative
Penicillic acid	*Penicillium puberulum*	Alsberg and Black, 1913	Gram-positive and Gram-negative
	Penicillium cyclopium	Oxford, Raistrick and Smith, 1942	Gram-positive and Gram-negative
Claviformin[1]	*Penicillium claviforme*	Chain, Florey and Jennings, 1942	Gram-positive and Gram-negative
Citrinin	*Penicillium citrinum*	Raistrick and Smith, 1941	Predominantly Gram-positive
Fumigatin	*Aspergillus fumigatus*	Oxford, 1942	Predominantly Gram-positive
Fumigacin	*Aspergillus fumigatus*	Waksman, Horning and Spencer, 1943	Gram-positive
Clavacin	*Aspergillus clavatus*	Waksman, Horning and Spencer, 1943	Gram-positive and Gram-negative
Aspergillic acid	*Aspergillus flavus*	White and Hill, 1943	Gram-positive and Gram-negative
Helvolic acid	*Aspergillus fumigatus*	Chain, Florey, Jennings and Williams, 1943	Gram-positive

*Patulin, which has recently been described by Raistrick *et al.* (1943), is identical with claviformin (Chain *et al.*, 1942, 1944; Crowfoot and Low, 1944), and reports about its efficacy in the common cold are conflicting (Stuart-Harris *et al.*, 1943).

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material. It can be conceived that if this is accomplished, the production of large numbers of related compounds by chemical manipulation will be possible and, just as the properties of the sulphonamides have been modified, so may those of penicillin. The therapeutic work so far done with very impure penicillin preparations may in a few years be looked upon as the first halting steps towards the discovery of a new range of powerful chemotherapeutic agents.

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Geology's debt to Henry Thomas de la Beche

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F. J. NORTH

Britain was the first country in the world to make an official geological survey of its land, and is still the best and most fully documented in this respect. Most of the credit for the original work is due to Sir Henry Thomas de la Beche, who for some obscure reason has never found a biographer. Dr North, who has had access to many of de la Beche's unpublished letters and diaries, here describes the circumstances in which the Geological Survey was initiated, developed, and grew into a permanent national institution.

The 'Geological Survey' of Great Britain was the first official undertaking of its kind in the world. Directly or indirectly affecting mining, civil engineering, building, water-supply, agriculture, and industry, it has increased our knowledge of the geology of Britain to a greater extent than would have been possible by private enterprise; but published records have very little to say of the circumstances in which it originated.

From *The First Hundred Years of the Geological Survey of Great Britain*, by Sir J. S. Flett (1937), we learn that 'the initiative appears to have come actually from the Ordnance Survey, which applied to Buckland, Sedgwick, and Lyell for a recommendation or report,' and that 'the reason why de la Beche took on the task of colouring Ordnance maps can now only be inferred.'

FIGURE 1 – *Sir H. T. de la Beche, C.B., F.R.S.* (*From a portrait in the* Illustrated London News, *17th May, 1851.*)

The first of these statements is a reasonable interpretation of remarks by certain presidents of the Geological Society of London. In 1834 G. B. Greenough reported that:

> Mr de la Beche, . . . acting under the direction of the Board of Ordnance, has produced a geological map of the county of Devon. . . . Let us rejoice in the success which has attended this first attempt of that Honourable Board to exalt the character of English topography by rendering it . . . more scientific.

Two years later Charles Lyell said:

> . . . An application was made by the Master General and Board of Ordnance, to Dr Buckland and Mr Sedgwick as professors of Geology in the Universities of Oxford and Cambridge, and to myself as President of this Society, to offer our opinion as to the expediency of combining a geological examination of the English counties with the geographical survey now in progress. In compliance with this requisition we drew up a joint report . . .

It is sufficient here to note that the report was favourable, and that Lyell concluded his reference to it by saying: 'I congratulate the Society that Mr de la Beche has been chosen to discharge an office for which he is so eminently qualified.'

de la Beche (1796–1855), almost alone amongst his peers and contemporaries in the geological world, has never been the subject of a biography, and search for material that might be used to remedy this deficiency has brought to light a large number of unpublished letters and diaries[1]. Some of these relate to proposals he made for geologically colouring certain Ordnance Survey maps, and show that the

[1] Most of these were kindly placed at my disposal by the late Colonel J. I. D. Nicholl of Merthyr Mawr, and Mr R. M. Dillwyn of Castle-upon-Allum, de la Beche's great-grandsons, and by the Director-General of the Ordnance Survey.

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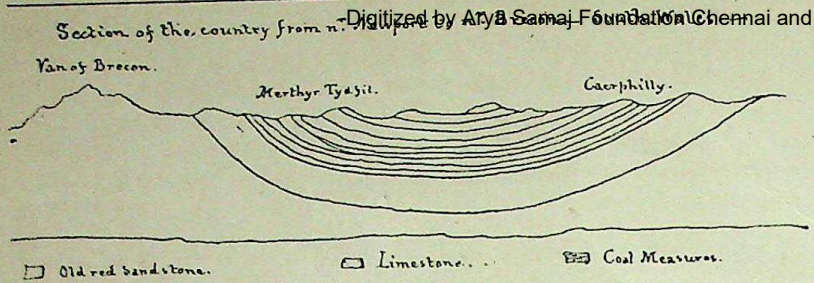

FIGURE 2—*A drawing from one of de la Beche's early notebooks* (1819). *This is the earliest known geological section across the South Wales coalfield, and is comparable to a generalized section that might be drawn today to illustrate an elementary text-book.*

Geological Survey had its origin in his perspicacity and owes its development to his administrative skill. The story provides another illustration of the debt we owe to the pioneers who helped to lay the foundations of the practical applications of science.

As a youth de la Beche entered the Military College at Marlow, but the peace in Europe at the close of the Peninsular War made him give up his military career, and, as he lived at Lyme Regis, in a region full of geological interest, his liking for outdoor occupation led him to collect rocks and fossils and to study the problems of their distribution. Deriving his income from an estate in Jamaica, he shared in the criticism directed against slave-owners, but in the West Indies he was disliked because he was genuinely interested in the welfare of his negroes. He would not, for example, allow his 'drivers' to carry whips, and finding that the officially appointed clergy did very little for the negroes, he arranged for a Wesleyan missionary to give religious instruction to those on his own estate, and refused to admit the legality of the High Commissioner's contention that he should have obtained the 'consent of the quarter session' before doing so.

Labour troubles in the early eighteen-twenties, when he visited the island, were sufficiently serious to make him write:

> Much as I desire speedily to return to my native cool land, the present depressed state of West Indian affairs has so diminished my command of the needful that I cannot exactly state when that may be.

Conditions grew steadily worse after his return to England, and in March 1832, not wanting to abandon a scheme for preparing a geological map of Devon, he asked for assistance from the Master General of the Board of Ordnance. He described the undertaking as:

> one that I had set out with the intention of accomplishing at my own proper cost, but in which I am defeated by the failure of certain funds I had intended to apply to that purpose. I am induced therefore to offer to your Honble. Board the fruits of my labours at a price that I am well assured will be considered very moderate . . .

The memorandum was long, but the essential proposals are worth quoting just as he made them:

> For the sum of £300, I undertake . . . accurately to determine the Geological structure of the district comprised within the eight sheets [of the Ordnance Map] specified, and to lay down the detail accurately to scale . . . in so clear and intelligible a manner as to admit of its being readily transferred to the Ordnance Copper Plates. I will also attach to the margin of each sheet an Index scale of colours descriptive of the rocks and beds comprised within it . . .

He proposed an adjustment in the price of the sheets to cover the cost of adding the geological particulars, and gave a detailed estimate of the profit the Board could expect to make on the transactions, viz. £92. 9s.

The proposal was referred to Lieutenant-Colonel Colby (then in charge of the Ordnance Survey). Colby had already displayed an interest in geology to the extent of permitting two of his assistants to make geological observations in the areas in which they were working, and in 1830 had issued a circular to his officers, outlining a 'System of Indicoclature' to be used in 'Geological Plans and Sections.' This contained twenty-five symbols and eight colours; but they related to kinds of rock (e.g. granite, porphyry, limestone), and not to their relative ages. 'Sands of the Chalk' were, for example, represented by the same colour as 'Sands of the Oolite,' and 'Coal Grit' by the same colour as 'Old Red Sandstone,' so that their use could not have resulted in a geological map as we now understand it, and as de la Beche envisaged it.

In his report Colby said:

> . . . Though I object to undertaking any responsibility for the accuracy of the Geological information, and also to any increase of price in the sheets containing the Maps of Devon, I have to report my opinion that the offer made by Mr de la Beche is highly advantageous to the Public.

He expressed doubt whether there would be any profit, but thought that the advantage of

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making the Ordnance Survey maps into 'perfect illustrations of the geological features of the country' would outweigh any financial considerations. Five weeks later de la Beche was informed that his proposal had been accepted, and the correspondence which followed illustrates the way in which he handled the varying and often difficult situations that arose before his scheme was finally launched.

I cannot avoid (he wrote) expressing my fears that one of these conditions, though excellent in theory, will not be found to work in practice; I allude to that which makes it incumbent on us to use no other colours . . . than those which have received the sanction of the Council of the Geological Society. Now if that Council was composed of men who understood the subject and were men of business and dispatch, nothing would be so easy as to have a speedy decision. . . . Unfortunately, however, this is not the case, and we have to arrange with a body, which, with the exception of Mr Greenough and myself, are far from having given the subject proper attention, and as for business and dispatch we must expect little from them. . . .

There seems no chance of determining the colours in the Council of the Geological Society for the present, and I am sadly afraid when they do determine them that they will not by any means be such as will reflect credit on the work, in as much as they will be settled by men who . . . would never have produced a decent Geological Map to accompany any of their memoirs, if it had not been for Gardner of Regent Street, who must have had the patience of Job to get through the work.

Already de la Beche had visions of a larger scheme than the one then under discussion, because in the same letter he said:

If publication . . . is to be delayed by these worthies of the Geological Society it will cut sadly into the calculations I have entered into as to the pecuniary advantages which the Ordnance may receive from the sale of these Geologically coloured Maps . . . and may prevent the Board of Ordnance from having anything further to do with the Matter than these 8 sheets. . . . This if possible should be avoided.

Colby was as anxious as de la Beche to avoid delay, and suggested that:

Any colours you think best can be used on the original manuscripts of the Geology, and when we have engraved the lines . . . on the Copper, a Copy can be coloured according to the decision of the Council.

The colour scheme was finally decided upon in consultation with Mr (afterwards Sir) Francis Chantrey.

When reporting early in 1835 that the eight sheets had been completed, de la Beche again raised the question of a more extensive survey:

I respectfully request that the Honble. Board will be pleased to examine the result of my labors: and if they shall find it desirable . . . I will willingly devote my time to the Geological examination of another portion of the country.

The Board decided to obtain expert opinion, and ordered that the work which Mr de la Beche has completed be referred to the President of the Geological Society, Dr Buckland and Professor Sedgwick, for their Report thereon, the Board being desirous of obtaining the best information the Country can afford before they come to any decision as to the extension of Mr de la Beche's labours. . . .

The report was lengthy but favourable, and included the following passages:

We regard its [the map's] publication as reflecting great honour on the Board of Ordnance, with whom it originated, and at the same time a benefit to European Science.

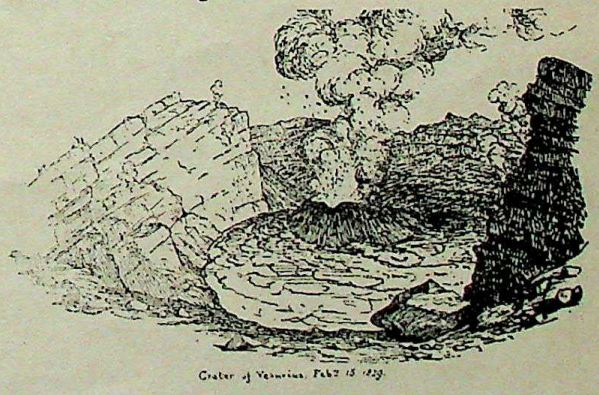
We are further of opinion . . . that it would be highly useful to the Nation to continue his [de la Beche's] services, in the extension of a geological survey on one uniform system over other parts of Great Britain.

When Colby had also reported favourably upon the new proposals the Board asked the Treasury for 'Authority to carry into effect the suggestions of the learned Professors . . . that the services of Mr de la Beche may be forthwith secured to the Department.'

Although friendly, the Treasury was cautious:

The Lords Commissioners . . . (it said) are well aware of the advantage with which such a labor

FIGURE 3 – *A sketch from one of de la Beche's notebooks* (1829). *For several years before suggesting that the maps of the Ordnance Survey should be geologically coloured, de la Beche travelled at home and abroad making geological observations, and his notebooks illustrate his keen perception and his skill in recording what he saw.*



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could be undertaken . . .; before however [illegible] can give their final consent, . . . my Lords desire you will move the Master General and Board of Ordnance to furnish them with some estimate of the time which they consider will be required for the entire completion of the whole undertaking.

de la Beche's reply was characteristically diplomatic: '. . . I beg to state that I consider that the Geological Map will keep pace with the Geographical Map, and consequently that both Maps will be completed at the same time.'

The Treasury, however, wanted something more definite than that. If, it asked, the completion of the Geological Survey is dependent upon the 'progress of the Geographical Survey,' how long is the latter expected to take?

After further consideration, it was reported that, calculating on the basis of the Devon maps, it would take 21 years to complete the part of England and Wales of which the Ordnance maps were already published:

> If, however, he received the aid of two or three competent assistants, Mr de la Beche considers that he would complete the part in 7 years. Estimating the rate of progress as above, . . . the Geological Map of England and Wales may be completed in about 10 years.

Permission to continue the work having been given, de la Beche went to Cornwall (on a salary of £500 per annum) and within a week we find him writing to the Chancellor of the Exchequer (Mr Spring Rice), proposing an additional activity:

> I beg respectfully to suggest, as the persons employed on the Geological Survey will have constant opportunities afforded them of collecting specimens illustrative of the applications of Geology to the useful purposes of life, that a collection of these specimens be placed in a room or rooms under the care of the Board of Public Works.

He amplified this suggestion in letters to the Office of Woods, and to Colby he wrote: 'I expect daily to hear from the Board respecting the Museum to exhibit the mineral wealth of the country. This is a matter which I have much at heart.'

About a month later he was informed that his plans were to be adopted, and that a house in Craig's Court [Charing Cross], London, was to be used for the purpose. In the following year he was able to report that: 'The specimens in the Museum are all labelled and the localities where they were obtained are properly marked on them.'

It was called the Museum of Economic Geology, and from it sprang first the Museum of Practical Geology in Jermyn Street, and then the Geological Museum at South Kensington.

So much for the inception of the Geological Survey and Museum; their successful development was due to de la Beche's determination not to be deflected from his purpose. A request for the establishment of a fully staffed and fully equipped organization would certainly have been refused, but little by little he cajoled or demanded

FIGURE 4 – *A sketch from one of de la Beche's early notebooks* (1819). *He recorded the personal aspects of his travels as well as their scientific results, and his notebooks contain many illustrations of contemporary modes of travel; this one depicts himself and his servant 'geologizing' in the Alps.*

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as circumstances dictated, and ably backed by Colby, who all along took a keen personal interest in the matter, he eventually got what he wanted.

In 1837, after receiving permission to transfer his attention from Cornwall to South Wales, de la Beche pointed out that his salary did not cover the expenses of the Survey on account of the

> constant system of movement which the service requires, and my necessary residence during the greater part of the year at Inns. . . . As I am quite certain it was never contemplated that the discharge of my duties should entail expenses beyond those which my salary would cover, perhaps you would have the goodness to mention the circumstances to the Master General and Board for their consideration. I look for nothing beyond the payment of necessary expenditure, and if £25 per quarter be allowed in lieu of travelling expenses, I will take the risk of such addition being sufficient to cover all expenses.

The Inspector-General of Fortifications did not view this request with favour. To him it 'appeared to be only granting, under the head of a travelling allowance, an addition of £100 a year to Mr de la Beche's agreement, which, if proper, should have been included in the first agreement,' but later he supported it because he supposed that 'a compliance with his request will expedite the publication, and therefore some saving may be expected by the earlier completion of the whole, when the salary would cease.' He naïvely assumed that the Geological Survey would automatically cease to exist as soon as the last sheet of the Ordnance map had been geologically coloured for the first time.

The correspondence, not altogether friendly on the part of the authorities, dragged on for eleven months. de la Beche firmly but respectfully upheld his claim, and at last was informed that 'although it is not strictly in conformity to precedent, £25 per quarter shall be allowed you to cover all travelling expenses without requiring the production of vouchers.' It took five weeks for the authorities to accept the proposal to colour the Devonshire maps, about the same time for them to agree to the extension of the work into Cornwall, a month to inaugurate a Museum of Economic Geology, but a year to settle a routine matter involving an expenditure of £25 per quarter!

When he wanted assistants, de la Beche asked first for a miner to help in the rough work, then for a person who could be trained in geological methods, and, having got the principle established, it was only a matter of time before he had gathered around him a small band of workers as enthusiastic as himself.

In 1839, realizing that he would not be able to complete the map of England and Wales in 10 years as he had supposed, he asked for permission to 'hire such geological assistants as I may consider requisite for the proper execution of the work.' When this request came to the notice of the Inspector-General of Fortifications his comment was: 'I know of no authority for the extensive view here taken of extending the Geological Research,' and he advised that nothing should be done until 'an appropriate estimate of the whole intended outlay' had been obtained. The result was that the Board of Ordnance expressed itself as being

> decidedly of opinion that it will never do to go on with this Geological Survey without some distinct rules by which the expense is to be governed. . . . By reference to the original arrangement it will be seen that a most material departure has already taken place from what was then proposed, and . . . what is now asked for will lead to an unlimited expenditure of time and money.

Asked to indicate how long the whole work would take, and how much it would cost, de la Beche said it was not possible to estimate 'the cost of Geological Surveys and the time necessary for their completion, as until some examination of a given area has been effected, no correct idea of the whole expenditure can be formed.'

Careful handling of the situation eventually resulted in an acknowledgment that it was not possible to foresee and to legislate for every contingency that was likely to arise, and at last Colby was informed that

> the only plan . . . will be, from year to year, to take such a sum as may be deemed advisable, upon which point the Master General and Board would from time to time avail themselves of your opinion and so check any extraordinary expense that may be proposed.

de la Beche was quick to act upon the recommendation, for in less than a month he was able to tell Colby: 'I have picked up one very clever hand as an assistant at 7/- per day, a regular good one he is, and I am now on the look out for others.'

The 'Return' for September 1839 contained two names, and in December the estimates for 1840 provided for *four* assistants. The question of a limit to the duration of the work was never raised again—the Geological Survey had become a permanent institution.

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The coloration of butterflies and moths

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G. D. HALE CARPENTER

Many species of Lepidoptera display close similarity to dead leaves, the resemblance often reaching a perfection of detail. Other species flaunt gaudy colours and appear to invite attention. Professor Hale Carpenter sets down some arresting facts concerning both types, and illustrates his article with examples of remarkable interest and beauty.

Coloration implies two ideas: the presence of pigment whose selective absorption of light results in colours which reach the eye, and the distribution of pigments to form pattern. Butterflies and moths, usually considered as creatures of sunlight or darkness, depend for their safety quite as much upon pattern as upon colour; not one is quite uniformly coloured.

Pigments differ in their durability under light, and Plate I reveals some striking facts. Collections long exposed to light show fading to different degrees; many butterflies fade little, and this also applies to day-flying moths; it would seem that they have been fitted with durable dress. But moths which hide during the day and fly only in darkness have pigments ill adapted for exposure, which show fading markedly. It will be noticed that pink or red tints are especially labile, and that the tawny orange colour, such as is shown by our Fritillary butterflies, is very durable: in figure 2 it has survived exposure better than the blackish melanins surrounding it. Very similar tints in butterflies may be produced by pigments of quite different chemical constitution (e.g. figures 25 and 27, or 26 and 30), an example of the widespread circumstance that Nature obtains similar results by very different means.

Butterflies and moths when at rest are often concealed by resemblance to dead leaves; these offer an immense variety of shades and patterns. Such species as *Kallima inachus* (figures 7, 10, 11, 13), by resembling a variety of leaves rather than one pattern, make it more difficult for a searching enemy to detect them, and consequently decrease the risk to any particular individual. The perfection of detail extends to the production of an appearance of a ragged or crumpled edge (figures 8, 12) and of discoloration by fungus growth (figures 7, 11). Dead leaves are often slit or holed, letting bright light through; this effect is produced in various species by a notch in the wing (figure 6), by a small area on the wing devoid of scales so that the transparent basal membrane permits the passage of light (figure 11), or by a patch of white pigment which by its brilliance gives the effect of bright light seen through a hole (figures 5, 8).

Objects being recognizable partly by shape, anything which detracts from the regular outline of a butterfly's wing will render it less recognizable. Such a type of coloration, shown in figure 9, is termed disruptive. The strong contrast between light and dark distracts the eye and masks the usual contour by which the outline of the butterfly is perceived.

The great majority of butterflies and moths are so coloured that, when at rest, they are concealed. This applies particularly to the *under* surface of the wings of butterflies, which alone shows when the insect is in complete repose. These cryptically coloured insects are generally edible by vertebrate enemies.

Others, however, flaunt gaudy colours before an observer, seeming to invite attention: these are said to be aposematic, or warningly coloured. The explanation is found in the association with such colours of tough bodily structure, emission of acrid odour, or even violent ejection of strong-smelling fluid which may be displayed as brightly coloured froth by a special attitude. The edibility of such aposematic species is of low degree and, provided there is an abundance of other, more edible, species to provide food they will be left alone. This avoidance of relatively distasteful species, however, must be based on previous experience which necessarily destroys a certain number. Consequently it is to the advantage of a distasteful species to be able to withstand rough handling, through its toughness, so that when released as unfit for food it has not suffered mortal injury. Further, since it is an advantage to such a species to be easily recognized for what it is, the more it facilitates recognition the better for it. As a matter of fact, such types have brilliant colours in simple, strongly contrasted patterns and do not show the beautiful shading and

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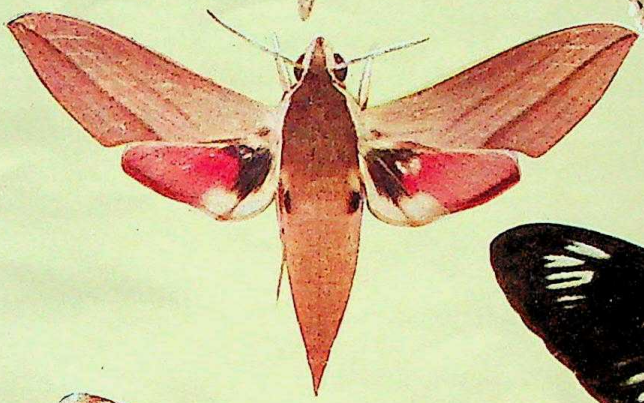

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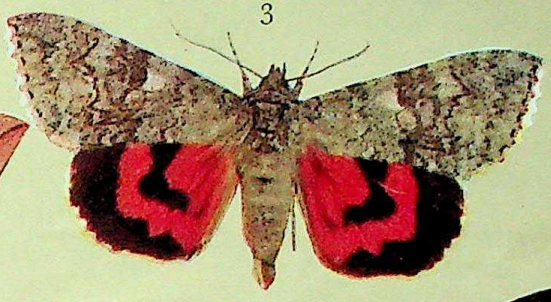

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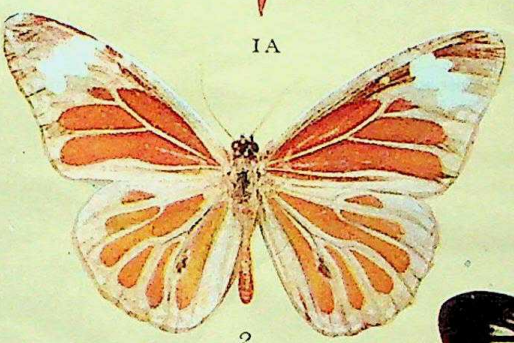

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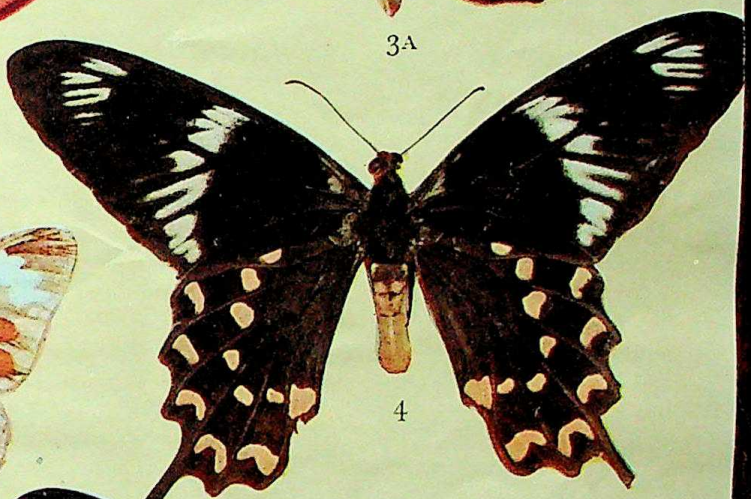

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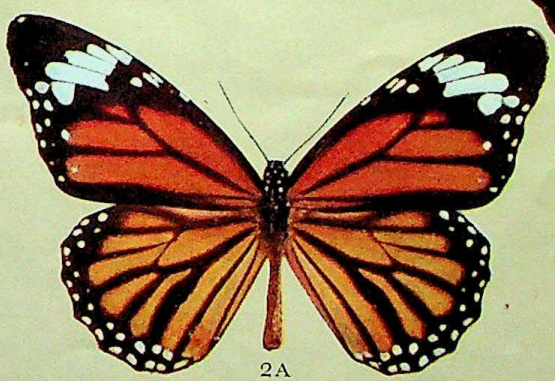

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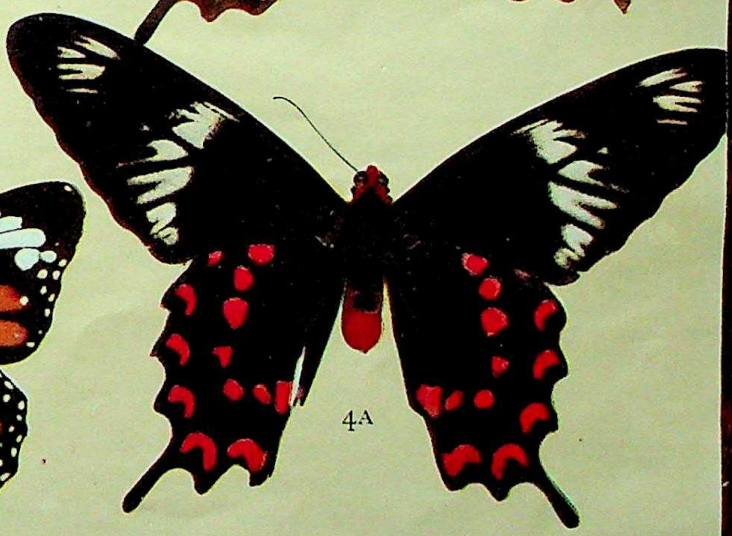

4A

Fading of pigments: *Pairs show the effect of prolonged exposure to light in the upper specimen, and a fresh specimen below.* 1 *and* 1A, *Sphingid:* Chaerocampa alecto *L. (India).* 2 *and* 2A, *Danaid:* Danaus plexippus *L. (India).* 3 *and* 3A, *Noctuid:* Catocala nupta *L. (Europe).* 4 *and* 4A, *Papilionid:* Polydorus hector *L. (India).*

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PLATE II

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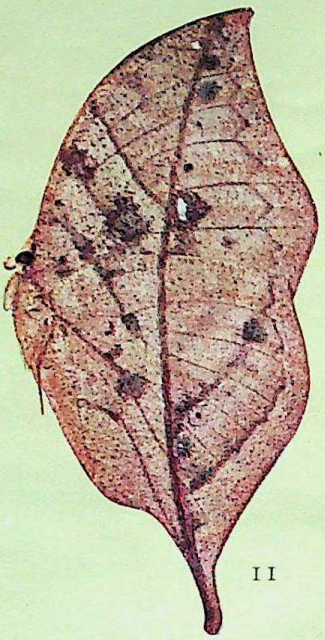

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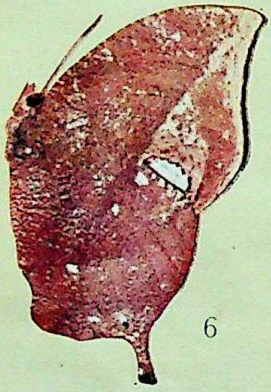

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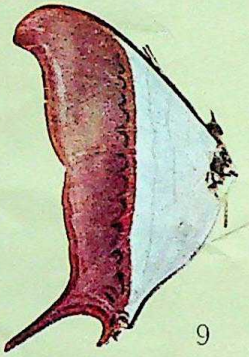

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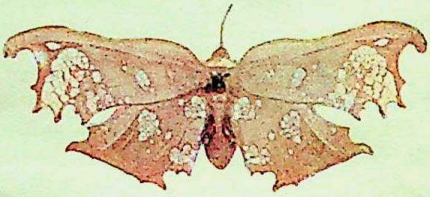

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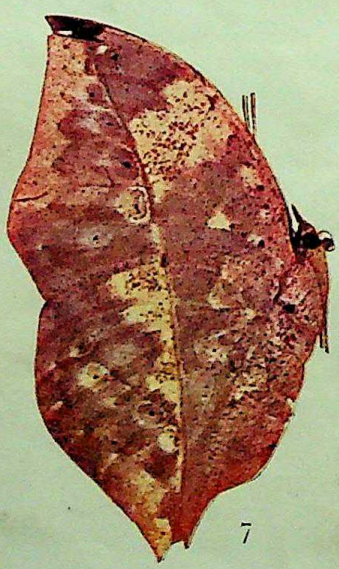

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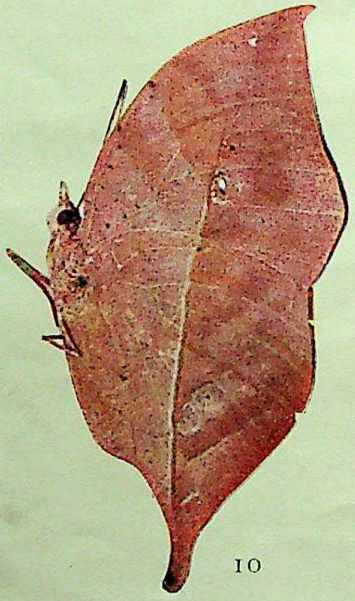

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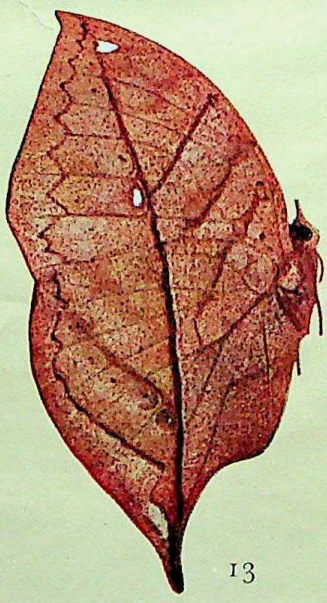

13

Cryptic resemblance to dead leaves: *The resemblance produces the effect of a torn leaf* (6, 8), *of fungus growth* (7, 11), *or of damage by a leaf-eating insect* (12). 5, *Nymphalid:* Doleschallia bisaltide *Cramer* (*India*). 6, *Nymphalid:* Anaea morvus *Fabricius* (*Tropical South America*). 7, 10, 11, and 13, *Nymphalids:* Kallima inachus *Boisduval* (*India*). 8, *Nymphalid:* Polygonia *c*-album *L.* (*Europe*). 9, *Nymphalid:* Marpesia coresia *Godart* (*Panama*). 12, *Thyridid:* Draconia rusina *Druce* (*Trinidad*).

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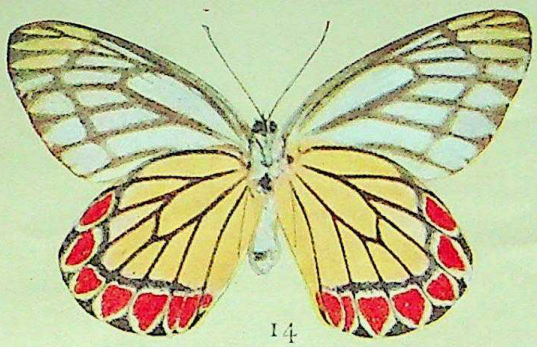

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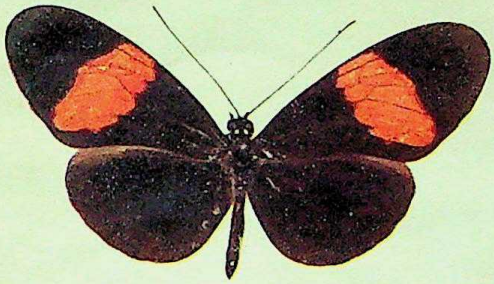

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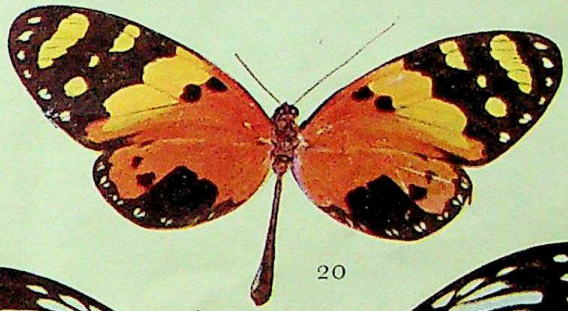

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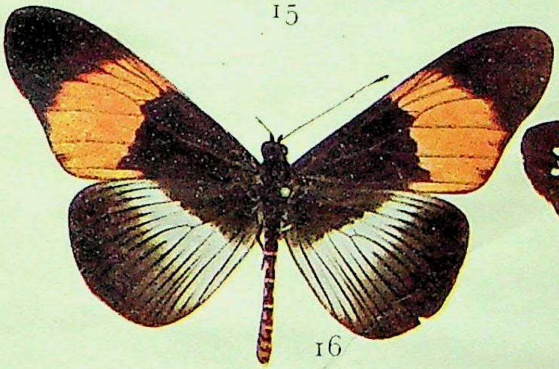

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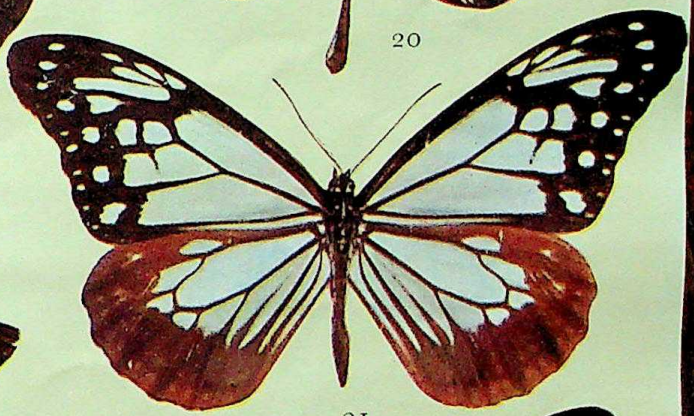

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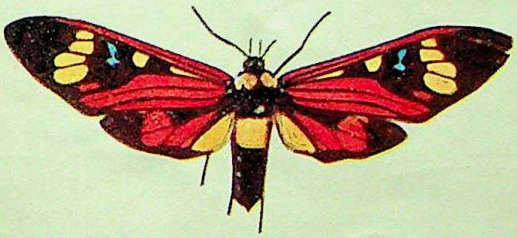

17

18

22

Warning colours: *Butterflies and day-flying moths advertise distastefulness by brilliant colours in simple patterns.* 14, *Pierid:* Delias eucharis *Drury* (*India*). 15, *Heliconid:* Heliconius hydaruis *Hewitson* (*Trinidad*). 16, *Acraeid:* Bematistes poggei *Dewitz* (*East Africa*). 17, *Syntomid:* Histioea meldolae *Butler* (*Peru*). 18, *Sarrothripid:* Eligma latepicta *Oberthur* (*Nyasaland*). 19, *Papilionid:* Polydorus hector *L.* (*India*). 20, *Ithomiine:* Melanitis egina

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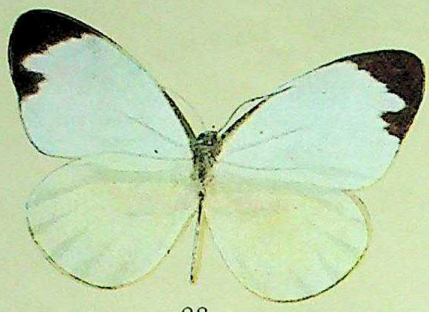

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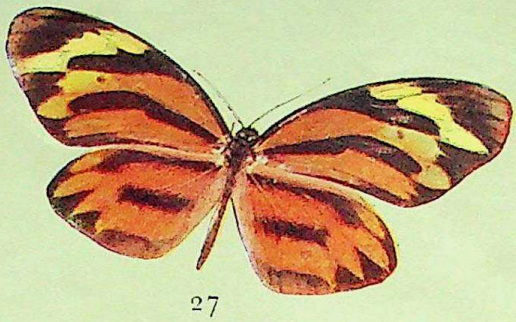

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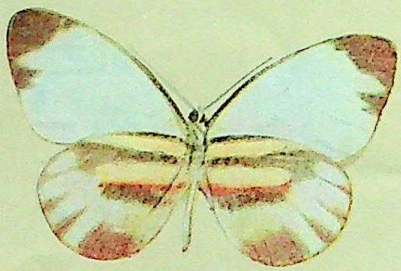

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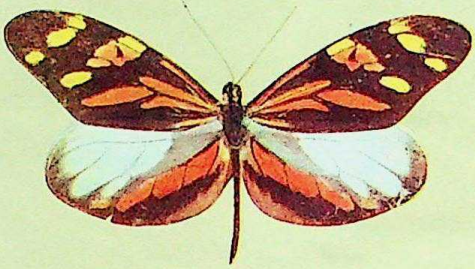

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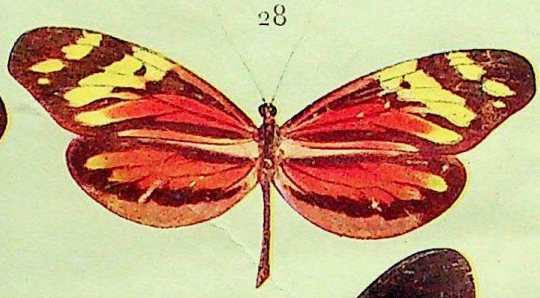

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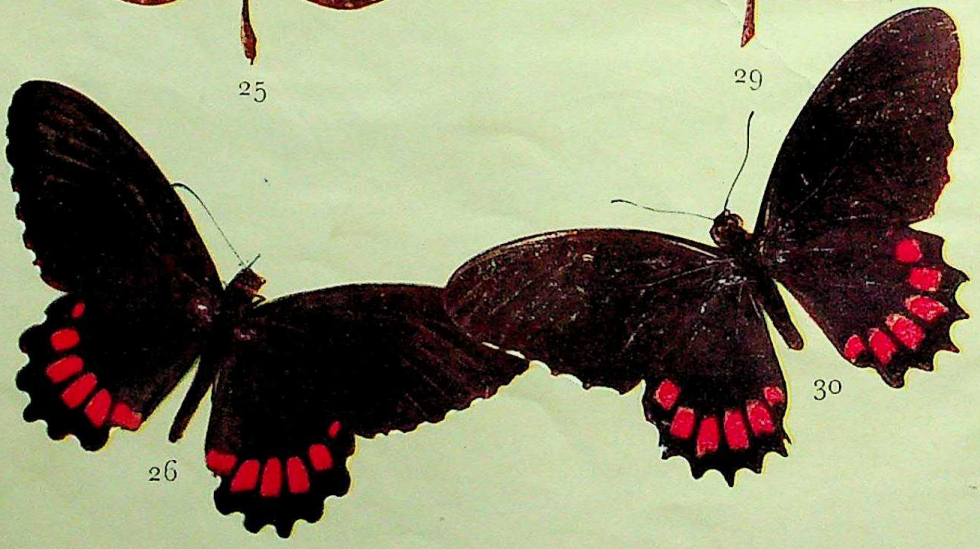

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30

Mimicry: *The distasteful* 25 *is resembled by the female* (27) *of a male* (23), *whose white upper surface is normal for the group to which it belongs: its under surface is shown at* 24. *Mimicry has gone further in another 'White,' of which the female is shown at* 29, *the male at* 28. *Number* 30 *mimics* 26, *belonging to a different section of the family.* 23 *and* 24, *Pierid:* Mylothris malenka *Hewitson, male* (*Venezuela*). 25, *Ithomiine:* Mechanitis veritabilis *Butler* (*Trinidad*). 26, *Papilionid:* Polydorus polyzelus *Felder* (*Guatemala*). 27, *Pierid:* Mylothris malenka *Hewitson, female* (*Venezuela*). 28, *Pierid:* Dismorphia praxinoe *Doubleday, male* (*Trinidad*). 29, *Pierid:* Dismorphia praxinoe *Doubleday, female* (*Trinidad*). 30, *Papilionid:* Graphium belesis *Bates* (*Guatemala*).

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complex design of cryptic species (compare Plates II and III). Thus there are two opposing classes of insects—cryptic, with softly shaded dull colours in complex patterns, which find safety in not being discovered; and aposematic, with strongly contrasted brilliant colours which advertise themselves freely as distasteful or even harmful. It is a point of considerable general interest that red and orange are by far the commonest aposematic colours, for the same reason that danger signals and berries are red.

Some aposematic insects, however, are not possessed of the qualities conferring distastefulness, and the associated habits. But so closely, although in superficial appearance only, may they resemble the genuinely aposematic species that they are readily mistaken for them in the field and may be passed over by an enemy not hungry enough to cope with an unpleasant meal. This is the phenomenon of mimicry in its true sense, or pseud-aposematic resemblance, in essence of the same character as resemblance to a stone, bird-dropping, or leaf. One species escapes by resembling an object of no food value; another, an object known to be distasteful. The second class is obviously in some danger, for the protection depends upon the amount of other food available: hence it is rare in Nature. Both types are explicable by the operation of natural selection upon material presented to it by variation.

The female sex in butterflies being intrinsically more variable than the male, it is not surprising that mimicry is more often shown by females (e.g. figures 27 and 29 compared with 23 and 28). Mimicry sometimes seems to have been developed from an initial variation on the under surface (compare figures 24 and 27). The pigment in mimics is often of completely different chemical constitution from that in the models. This is shown well by the 'whites' and their models, and the two 'swallow-tails' (figures 26–30) on Plate IV. The red pigments of the two latter react very differently to simple chemical tests, as shown by E. B. Ford, who has discovered five different types of red pigment in Lepidoptera. This disposes of the facile argument that the similarity in model and mimic may be due to consanguinity.

Very interesting is the case of the African swallow-tail *Papilio dardanus*, which occurs over most of continental Africa south of the Sahara. The male varies little; the female, never like the male, mimics a number of widely different butterflies. In Madagascar, however, the ancestral form occurs with the female much like the male; in both sexes the paler pigment is brilliantly fluorescent in ultra-violet light. This is not so in the mimetic females, in which there has been a chemical change from the ancestral non-mimetic type.

Another kind of polymorphism is seen in countries where there is a great seasonal change in the climate, with a pronounced dry season. Most remarkable results were obtained when naturalists proved by breeding that butterflies of widely different coloration, with important differences of shape and size, were truly the same species. *Precis octavia*, common in Africa, appears in the dry season in an intensely blue form with the under side blackish brown and mottled. During the wet season it is replaced by a smaller, salmon-red, form with the under side of the same colour. *Charaxes zoolina* in the wet season is a greenish white butterfly above and below, with short black bars; in the dry season it is of the russet colour of a dead dried leaf with the under side particularly leaf-like. It will be noted that the dry-season coloration produces more effective concealment when the butterfly is at rest, the time of greatest danger. This is understandable if it be remembered that the dry season is the time of great scarcity of insects, so that there is greater danger to any particular species. But during the wet season with its abundance of food the stress is diminished, and whatever the reason for the bright coloration it has not been countered by natural selection.

Difference in coloration between male and female, or sexual dimorphism, is widespread among butterflies, but there is little direct evidence to account for it. The female, unless mimetic, is usually of more sober colouring, and therefore less conspicuous. In the case of spiders, however, the males in courtship make elaborate use of brightly coloured areas displayed by special attitudes. Dragon-flies show sexual dimorphism to a marked degree, and the writer witnessed in Africa a remarkable display by the brightly coloured male of *Libellago caligata*. The basal segment of each leg is expanded to form a thin surface, brilliantly white anteriorly, scarlet posteriorly. A male was seen courting a dull-coloured female which was sitting on a grass stem: it repeatedly described an arc of a circle in a horizontal plane in front of her, passing from one side to the other, facing her with the legs held so as to display the shining white anterior surface. The red posterior surface would be visible later when the female had been seized by the neck and carried off in the marriage flight.

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Polythene

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J. C. SWALLOW

By the polymerization of ethylene under high pressure, a series of new polymeric hydrocarbons of high molecular weight has been produced on an industrial scale. These plastic materials, to which the generic name of polythene has been given, have excellent electrical properties combined with unique physical properties, and are therefore of considerable interest and growing application as dielectrics in the field of electrical engineering.

During the last ten years very great advances have been made in the laboratory synthesis and full-scale production of high molecular weight polymers. Many of these are finding outlets in the electrical industry, the future of which will depend to an increasing extent on the development of new dielectrics in which are combined the chemical, mechanical, and electrical properties necessary for use at the high frequencies and voltages now demanded.

Polythene is a new material now established in this field, and is a product developed by British research. Apart from being produced at pressures higher than those used in any other industrial chemical process at the present time, it is unique in being the simplest synthetic thermoplastic, since it is composed of long methylene chains ($-CH_2-CH_2-CH_2-CH_2-$) of 1,000 units or more. In consequence of its structure it has all the more desirable electrical properties associated with hydrocarbons, such as low dielectric constant, low power loss, and small water absorption, combined with good mechanical properties.

The story of the synthesis of polythene started several years ago in the laboratories of Imperial Chemical Industries, where it was decided to study the effects on chemical reactions of pressures much higher than those hitherto used in chemical industry, the highest pressure employed at that time being 1,000 atmospheres in the synthesis of ammonia.

P. W. Bridgman and other workers had studied the properties of matter up to pressures of 25,000 atmospheres, and the effect of high pressures on chemical reactions had been examined by J. B. Conant and E. Cohen and his school, Conant heaving measured the effect of very high pressures on the rate of polymerization of isoprene, dimethylbutadiene, and styrene.

It was decided, therefore, to carry out experimental work at pressures above 1,000 atmospheres, and the range was later extended to 12,000 atmospheres. In the early work certain selected liquid reactions were studied in small-scale apparatus in which it was possible to measure fairly accurately the effect of pressure on rates of reactions at different temperatures [2], [4], [5], [6]. Later advances in technique made it possible to examine gas reactions at these pressures, and in the course of this work it was found that ethylene could be polymerized to a flexible, tough, crystalline solid with a fairly sharp melting-point of about 110° C.

It was soon discovered that this reaction, which has a very large heat of polymerization, could also result—if the heat of reaction were not adequately dissipated—in an explosive decomposition to carbon and gases. Before further laboratory work could be undertaken, safety devices had to be perfected to protect the investigators and the equipment; and at a very early stage in the work the closest collaboration was necessary between the chemist, the physicist, the metallurgist, and the engineer—who had to produce apparatus which would withstand working pressures of the order of those occurring in a gun. One new device was a self-tightening pressure-joint, known as the wave-ring joint, which proved invaluable in subsequent operating plant. Eventually the novel chemical engineering technique required to enable a continuous process to be operated at the selected working pressure [3] was successfully devised.

Whilst a large number of organic compounds containing the vinyl grouping $CH_2=CH-$ have been polymerized to solids, many of them of great technical importance, yet in the case of ethylene—the simplest of the series—it had not been possible in previous work to obtain anything but oils of short chain-length. Long-chain solid hydrocarbons had been produced by various chemical syntheses such as the decomposition of diazo-methane, the products having a mean

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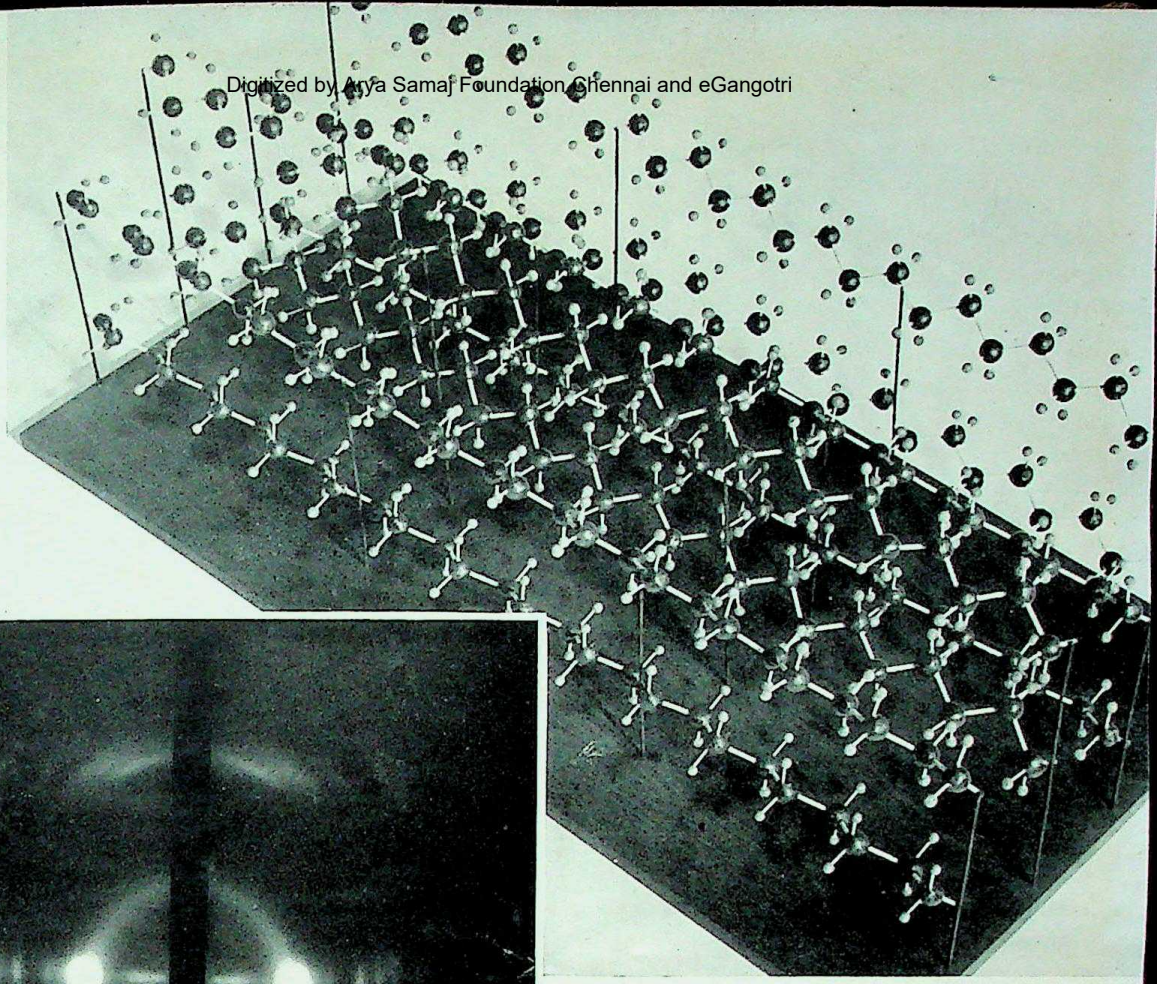


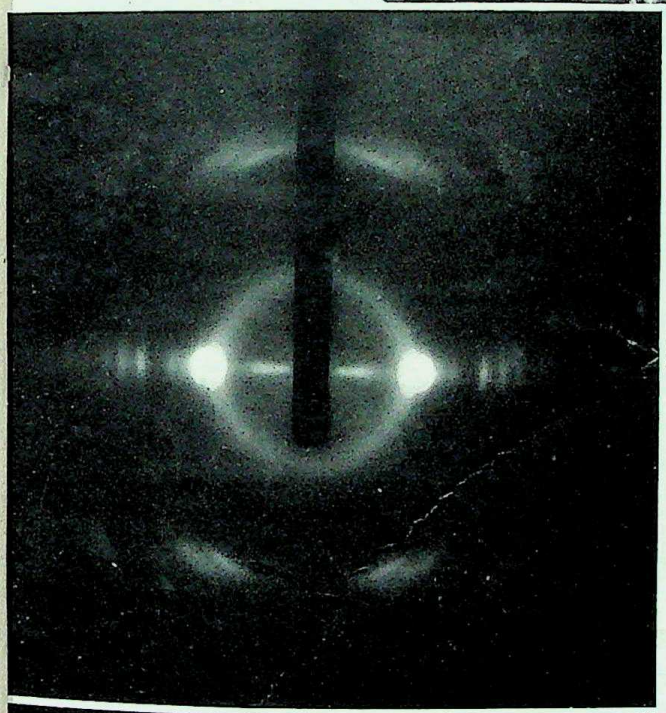
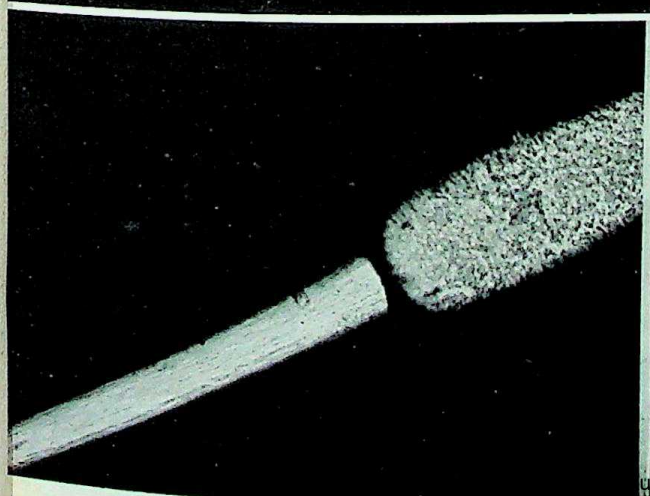


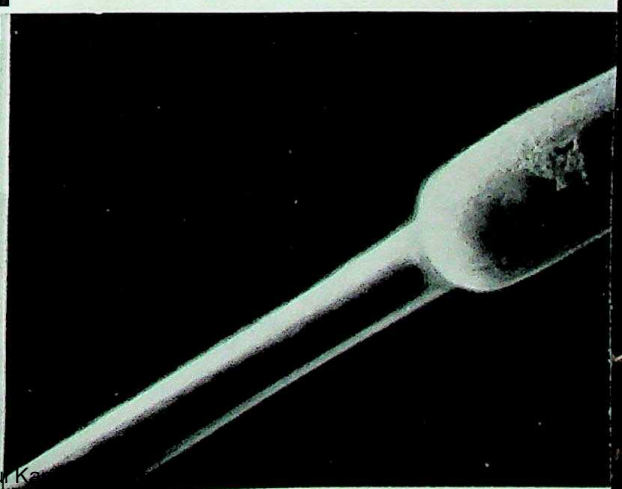
FIGURE 1 (*above*) – *An atomic model of the crystalline f polythene constructed to scale from the results of X-ray deter*

FIGURE 2 (*left*) – *X-ray picture of oriented thread shou orientation.*

FIGURE 3 (*bottom, left*) – *Cold drawn fibre between crosse the* 45° *position, showing the difference between the oriente oriented portions.* (× 80.)

FIGURE 4 (*bottom, right*) – *Cold drawn fibre of polyth ground illumination* (× 80.)





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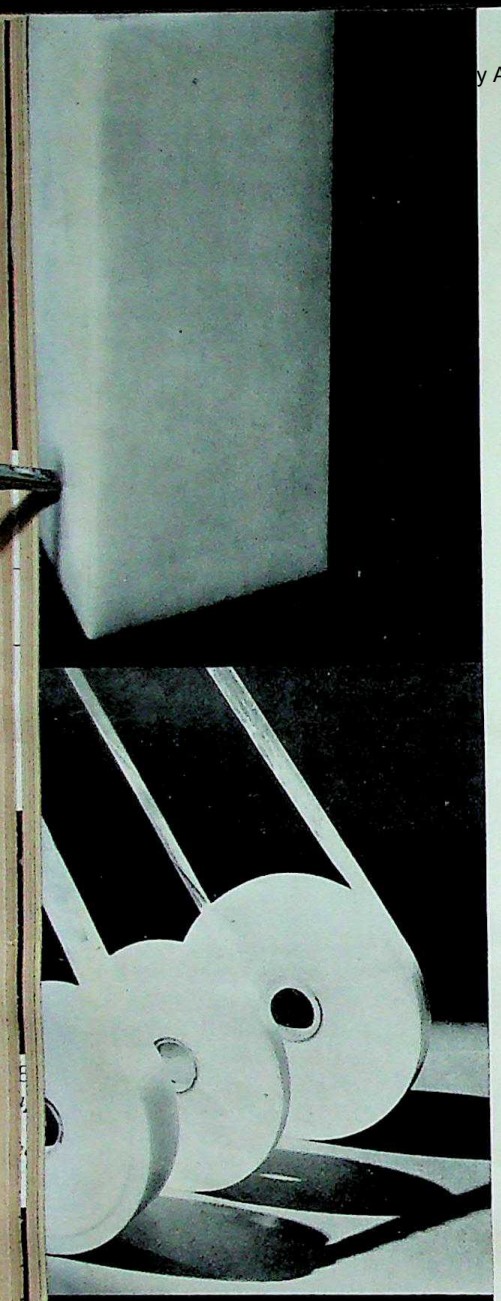
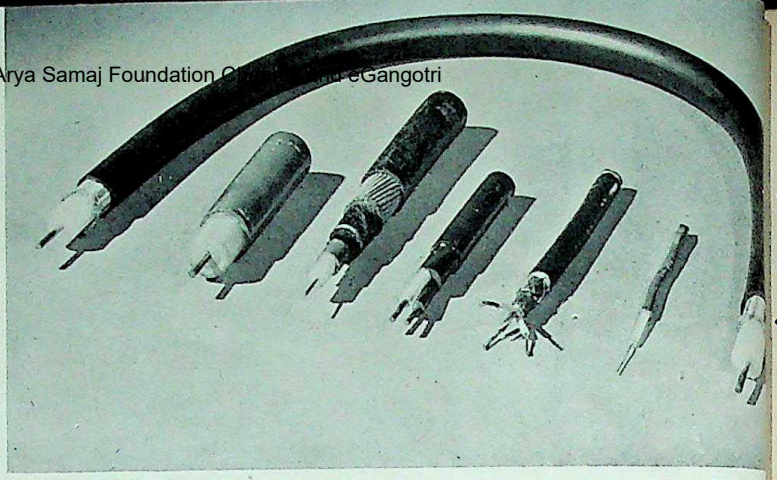




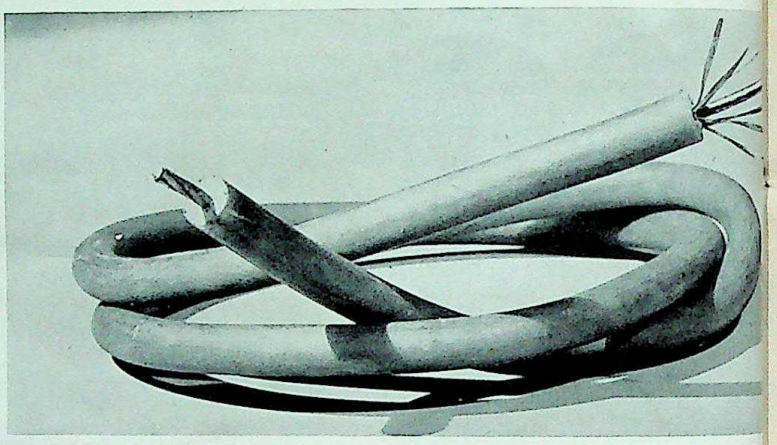


FIGURE 5 (*top, left*) – *A large container made by extrusion moulding i normal extrusion machinery.*

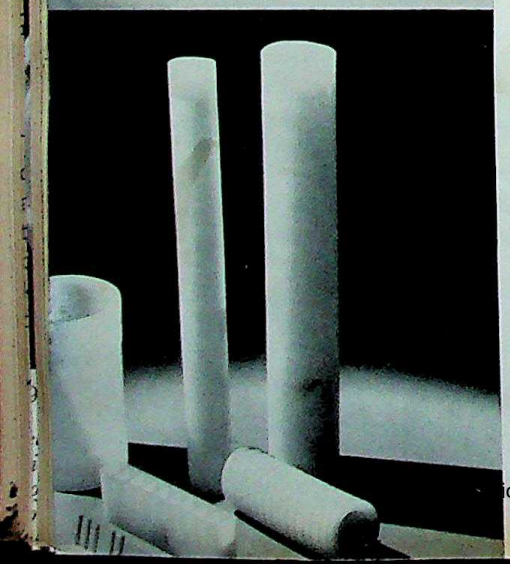
FIGURE 6 (*centre, left*) – *Film 3 mils thick made by extrusion.*

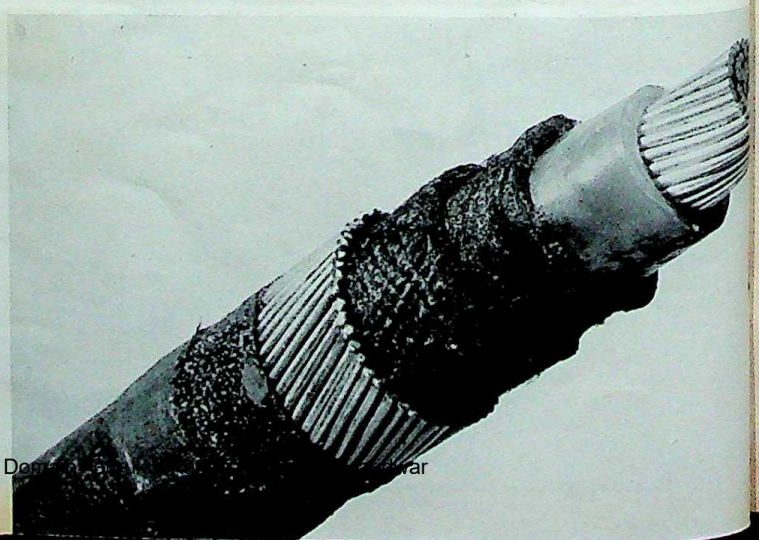
FIGURE 7 (*bottom, left*) – *Examples of flawless mouldings and of machined p from rod. The smaller examples were made by injection moulding.*

FIGURE 8 (*top, right*) – *Various types of high-frequency cables with poly insulation. The larger cable is protected on the outside by a sheath of plasti polyvinyl chloride.* (*Manufactured by Telegraph Construction and Maintenance Li*

FIGURE 9 (*centre, right*) – *A submarine cable core insulated with polythene plasti with polyisobutylene, which shows the high flexibility.*

FIGURE 10 (*bottom, right*) – *A section through a 440 volt power cable insulated polythene, which has been in service for several years.* (*Manufactured by Johnson and Philipps Li*





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chain-length of 170 carbon atoms. Substances of still higher molecular weight, of the order of 8,000 or more, were obtained by Fischer during the catalytic hydrogenation of carbon monoxide, but all such products were brittle waxes. By the new high-pressure process, therefore, it had been possible to produce the longest unbranched straight-chain hydrocarbon yet made by synthetic methods. Early in the work it was decided to make a detailed examination of the structure by X-ray analysis, and as a result of this it was shown that the product consisted of crystalline regions of orthorhombic symmetry, of unit cell dimensions a = 7·40 A, b = 4·93 A, c = 2·53 A [2]. Figure 1 shows a model of the crystal structure.

The chemical properties of this long-chain hydrocarbon are those which are to be expected from its structure and from its chemical composition, but it is these properties in combination with its mechanical properties which make it of such great technical interest. Further, its properties, both chemical and physical, are dependent on the molecular weight distribution in the product; this in turn is affected very markedly by the conditions of synthesis, which can be varied widely. It has been found that the most satisfactory method of classification of different polythenes is by the measurement of the liquid viscosity of the molten polymer at 190° C in a viscometer of special design. This method has the technical advantage of giving a measure of the extrudability of the product in extrusion machinery.

The solubility of the present commercial product in most organic solvents is very low at ordinary temperatures. It increases fairly rapidly between 50–70° C, although very high molecular weight products are not readily soluble in any solvent even above the melting-point, and show very rubbery characteristics at temperatures over 100° C. Polythene is unaffected at room temperature by such reagents as hydrochloric and nitric acids or 50 per cent. caustic soda, but it is attacked strongly by chlorosulphonic acid. At higher temperatures, in the neighbourhood of 100° C, it is still unaffected by hydrochloric acid and 50 per cent. caustic soda, but is attacked by nitric and sulphuric acids. Because of its saturated nature it is affected by ozone to a very much smaller extent than rubber, and this—as in the case of many other plastics—is an important property in electrical applications.

Polythene can be chlorinated in solution or suspension to give products with varying amounts of chlorine in the chain, and a series of plastic products—the mechanical properties of which depend on the chlorine content—can be produced, ranging from rubbery to hard solids. Polythene when hot oxidizes in air, but, as would be expected from its constitution, to a very much smaller extent than rubber. Recently it has been found that the introduction of suitable anti-oxidants inhibits the oxidation almost entirely, in the temperature range required for fabrication. This fact is of importance in the technical applications of the product, since oxidation is accompanied by a rise in power factor owing to the introduction of polar groups into the chains. When oxygen is excluded and polythene is heated in a high vacuum, it remains unchanged up to temperatures of 300° C. Above this temperature chain breakdown occurs, and brittle waxes, greases, and oils are formed.

Whilst, then, the product behaves chemically in a manner to be expected from its structure, its physical properties are unique for a saturated hydrocarbon; it is tough and flexible and possesses very great impact strength.

Polythene is a crystalline plastic, and its mechanical behaviour closely resembles that of the other polymers in this class, such as nylon, the vinylidene chloride polymers, and the natural products gutta-percha and balata. On applying tension to a test specimen it elongates in a regular manner over the whole length until the stress has reached a critical value, normally about 100 kgm. per square centimetre, and at this point the specimen separates into two regions, the drawn and the undrawn, separated by definite shoulders, as can be seen clearly in figure 4. This remarkable behaviour is of very great interest, both scientifically and technically. The ratio of the cross-sections of the two regions depends to a certain extent on the nature of the polythene and on the conditions of the drawing process, but is generally about 4 or 5 to 1. As the cold drawing process takes place, elongation proceeds at nearly constant stress until the specimen is cold drawn over the whole length and has increased four- or fivefold in length.

As in the case of other polymers of this kind, the orientation is clearly shown by examination under the polarizing microscope or by X-rays, which reveal a characteristic fibre diagram (*see* figure 2). It is now possible, in the case of crystalline polymers, to picture the change which takes place in the drawing process. Undrawn polythene consists of spherulitic aggregates of ordered regions or crystallites which can be seen under the

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polarizing microscope. The crystallites are to be regarded as ordered regions from which the chains project and are continued into non-oriented amorphous regions and into other crystallites. The sizes of the spherulites can be varied by thermal treatment; thus, by shock cooling, thin films can be made which are more transparent and flexible than ones which have been slowly cooled, and such films will cold draw more easily and at a lower stress. During the initial stages of stretching, orientation of the crystals takes place and can be detected by measurement of birefringence or by X-ray photography. On cold drawing, the crystallites are pulled into approximately parallel orientation, the long molecules becoming parallel to the direction of drawing; and during the process the crystals may be to some extent broken down to smaller ones. There may also be some reunion—in other words, recrystallization may occur.

On heating at temperatures below the melting-point, this state of order tends to disappear, and the specimen will retract. The orientation can, however, be completely removed only by heating above the melting-point, although in the case of polythene of very high molecular weight, and therefore of very high liquid viscosity, extrusion or stretching produces some orientation of the molecules even above this temperature. It is of interest to compare this phenomenon with the stretching of rubber, where the rubber molecules themselves are oriented by stretching until crystallization takes place. This disappears on releasing the stress, because the freedom of rotation in unsaturated substituted chains is greater than in the saturated polythene chains at room temperature. However, rubber at low temperatures will crystallize and will also show the phenomenon of cold drawing.

The X-ray diffraction pattern of polythene shows the presence of amorphous as well as crystalline regions; and the relative amounts of the two are of great interest, not only in the case of polythene but in the case of other crystalline polymers, since it has been found that slight changes can profoundly affect some of the more important mechanical properties. Examinations of the changes in physical properties (such as density and specific heat) with temperature indicate that there is a regular but increasingly rapid decline in the crystallinity of polythene as the temperature rises, the final traces of crystalline material disappearing at the melting-point.

Whilst polythene for many purposes requires no plasticizer, a means of controlling the softness is of value. The most satisfactory plasticizer has been found to be polyisobutylene of high molecular weight, which being rubbery gives the polymer a useful plastic range; it does not affect the dielectric constant or power factor, since it itself possesses a hydrocarbon structure. Amounts as small as 10 per cent. increase the flexibility of polythene at low temperatures; but changing the molecular weight distribution by altering the conditions of the synthesis produces the same effect without any plasticizer.

The large variations that can be obtained in low-temperature flexibility of polythene, which in the early stages of manufacture were little understood, made it necessary to examine in greater detail the effect of the molecular weight distribution on the mechanical properties. Measurement of distribution by such methods as fractionation and the ultra-centrifuge is tedious and difficult, and it has been found that other properties such as the solubility and the viscosity of the polymer in the molten state can be used to determine changes in distribution qualitatively. As a result of these studies it may be said that the tensile strength, the impact strength, and the flexibility at low temperatures are improved by an increase in average molecular weight, whilst for a given average there may be an optimum distribution of molecular weight. The deleterious effect on the mechanical properties (particularly the low-temperature flexibility) of an unduly large proportion of low molecular weight material has now been abundantly demonstrated. High molecular weight polythenes of higher tensile strength have been produced which are also flexible at —100° C, but these materials are somewhat more difficult to process with the machinery used for handling the normal commercial product. This is in striking contrast to amorphous polymers which, when heavily plasticized to give increased low-temperature flexibility, become weaker at ordinary temperatures.

In the case of the electrical applications in which polythene has been used already, and may be used more in the future, the combination of the electrical and mechanical properties is all-important. The low power factor of 0·0002–0·0003, whilst not being independent of frequency, shows only a sluggish variation over the widest range examined; and because the water absorption and permeability are so very small, it is practically independent of humidity, a fact of very great practical importance. These properties

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have already established polythene as a coming insulant for communication cables. The high breakdown voltage of polythene, combined with its other electrical properties, makes it attractive also as a possible insulant for high-voltage cables, provided that the difficulties due to the large thermal expansion can be overcome, and that the extrusion of the plastic can be carried out in practice with complete absence of voids. In extruding polythene or mixtures of polythene and polyisobutylene over wire, normal rubber screw forcing machines, preferably of the roller feed type, are used. The barrel temperature must be above the melting-point of 115° C and the temperature of the die should be between 130–160° C, depending on the liquid viscosity of the polythene used. If the die temperature is too high, excessive cooling of the extruded sections will be required, which will tend to cause voids in the extruded section. Where it is desired to protect the cable with an abrasion-resistant sheath, plasticized polyvinyl chloride compositions rather than rubber should be used, since sulphur diffuses into polythene.

The properties of polythene make it a very desirable material, in common with other plastics, for many purposes in which chemical resistance is of importance. The fact that above its melting-point it is a liquid which can be pumped at comparatively low pressure by normal extrusion machinery makes the production of large flawless mouldings possible by the technique of extrusion moulding. In this technique the plastic is injected by means of an extrusion machine into a mould constructed to stand about 200 lb. per square inch, provided with an injection hole which is clamped against the nozzle of the extruder. For large mouldings it may be necessary to heat the mould to 90–100° C. Small blowholes for the escape of air are provided at points removed from the extrusion nozzle, and when the polythene comes through them the mould is shown to be full. Cooling is started at the point furthest from the nozzle, the pressure being maintained until the mould is full. Tubing can be made by extrusion or, in the case of larger diameters, by welding sheet which has been produced by slicing blocks in a cutting machine. Powder of suitably small particle size can be successfully sprayed, by means of a gun similar to that used for spraying metals, to give coherent films on metal surfaces, and this offers the most convenient method of coating objects of irregular shape.

Films of very low water permeability can be produced from solution or by extrusion, although the latter method is to be preferred except where very thin film is required, and the mechanical properties can be varied by the conditions of manufacture. Thus, if extrusion is followed by rolling, orientation occurs in the direction of rolling, and the strength is greater in the longitudinal than in the transverse direction. The conditions of cooling affect the transparency of the film to a marked degree, shock cooling producing small spherulites and greater transparency. Fibres can also be produced, and the most interesting variations in orientation can be obtained, leading to different mechanical properties, and these are being further studied at the present time. In the development of technique for the fabrication of polythene, the crystalline nature of the material must be kept constantly in mind. Many uses have been found for the material, and many more will undoubtedly appear when opportunity occurs again for developing them after the war.

Quite apart, however, from the present and future technical applications, work on polythene is adding greatly to our knowledge of hydrocarbons and high polymers generally. It is the simple structure of the methylene chain that makes it such an attractive starting material for the systematic study of mechanical, chemical, and electrical properties of high polymers. Such work is more difficult, and almost impossible, when more complicated molecular systems are chosen.

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The chemical destruction of forest pests

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LEON L. OSSOWSKI

In virgin woodlands and forests there is a natural equilibrium between plant and animal (including insect) life. When man interferes, for example by the regimented planting of conifers, the balance is likely to be disturbed, and insect pests may flourish under the new conditions. The Head of the Forestry Department in the Polish Ministry of Reconstruction here describes some of these pests and the chemical counter-measures taken against them.

The steady increase in the number of insects harmful to woodlands, such as the nun moth (*Liparis monacha* L.), the pine looper (*Bupalus piniaria* L.), the pine noctuid (*Noctua piniperda* Panz.), and the pine moth (*Dendrolinus pini* L.), among the order Macrolepidoptera (large butterflies and moths), and, among the order Hymenoptera, the pine sawfly (*Lophyrus pini* L.), presents a serious forestry problem. It is chiefly conifers that are threatened and rarely deciduous trees. Various more or less successful means of combating these insects are at the disposal of foresters.

Before giving a description of the present scientific position as regards control measures, something should be said about the magnitude and causes of the outbreaks of insect plagues in the last fifty years, the extent of effective control, and the development of the most important methods hitherto elaborated.

Without definite figures it is impossible to realize the enormous damage done by these insect pests. In 1890, 12,000 acres of spruce in Bavaria [2] were completely destroyed by the nun moth. In 1918–23 the same insect attacked in Czechoslovakia about 600,000 acres of spruce (and pine), of which 70,000 acres were entirely ruined. In Bavaria [1] in 1895 the pine looper attacked about 100,000 acres of coniferous woods, in consequence of which 5,000,000 cu. ft. of timber had to be felled. In the past two decades the pine looper, the pine moth, and pine noctuid severely ravaged woods in Central and Eastern Europe, laying waste in the years 1921–25 about 200,000 acres of softwoods in the provinces of Brandenburg and Mecklenburg, and 250,000 acres in Poland.

Again in the years 1931–33 the cost of fighting the pine noctuid in one province of Poland alone amounted to £140,000. The foregoing figures represent only a small part of the havoc wrought by moths. It is during the past century that insect plagues have become more serious. This is undoubtedly because man by his activities has upset the natural balance of woodland life. The replacement of natural forests, with trees of different kinds and different ages, by conifers, generally of one species and of uniform age, has given the caterpillars of pine moth, noctuid, and looper, the larva and adult insect of all pine shoot beetles (*Myelophilus*), and other destructive insects, abundant supplies of suitable food. Nature has protested, by infliction of heavy disasters, against unnatural innovation upon the original and natural form of the primitive forest. The modern forest has no chance of self-regulation, and even a slight disturbance may suffice to upset its equilibrium.

The course of such an insect plague takes a characteristic form, in respect of the period and manner of the outbreak and its decline, which reminds one of the temperature curve in human diseases. Five stages in the development of a forest insect pest can be distinguished: (i) the initial stage, in which the first stimulus is given to an increase in insect population; (ii) the prodromal stage, in which the harmful symptoms are noticeable, though not dangerous; (iii) the eruptive stage, which is the most dangerous and causes a complete defoliation; (iv) the crisis, which leads to (v) the stage of abatement, during which the mass-increase generally disappears and the insect population returns to normal. A picture of the course of the disaster can be given by curves, reflecting the rapidity of its development.

Figure 1 shows observations of the various stages of the development of the pine looper, made during 1925–36 in a 0·5 hectare sample plot of a

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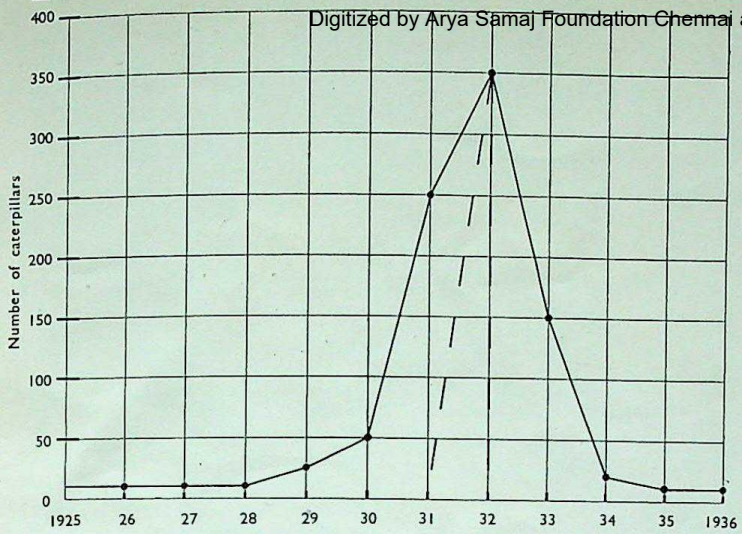


FIGURE 1

1925–28, 34–36: *normal years.*
1928–30: *two years of initial stage.*
1930–31: *prodromal stage.*
1931–32: *eruptive stage and crisis.*
1932–34: *stage of abatement.*

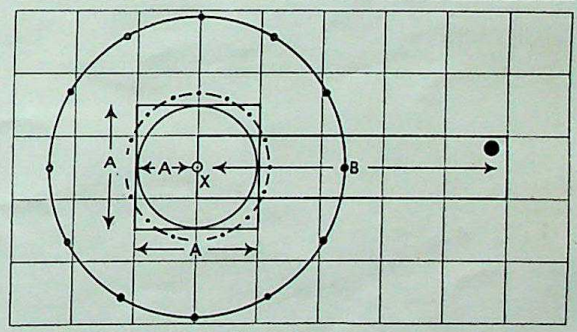
45-year old European pine (*Pinus sylvestris*) plantation.

The magnitude of an insect plague is determined by climatic and other factors, especially the presence of insect parasites. Every noxious insect has a group of parasites, principally *Ichneumonidae*, *Braconidae*, and *Tachinidae*, which chiefly infect the grubs and caterpillars. One may note some parasites found on the pine noctuid, the pine looper, and sawflies. On the first of these live [15] *Ernestia rudis* Fall., *Ichneumon pachymerus* Htg., *Trichogramma evanescens* Wetw.; on the second, *Cordiceps militaris*, *Ichneumon nigritarius* Grav., *and I. binunulatus* Grav.; on the third, *Externus cingulatorius* Holmgr., *Spilocryptus nubeculatus* Grav., *Externus oriolus* Hart., and many others. The importance of the parasites is slightly diminished by the presence of hyperparasites upon them, e.g. on *Tachina larvarum* the hyperparasite *Phygadeuon Schimitscheki* Fahringer [9, 10]. Microfungi, as *Isaria* sp. and *Fusarium* sp., also exercise no small influence on the course of a plague.

Science has made progress in detecting signs of an approaching outbreak, based on a more exact knowledge of the life-habits of various insects. Whereas the caterpillars of the pine moth creep down the tree trunk in autumn in order to spend the winter (as caterpillars) close to the bole under the surface of the ground, the caterpillars of the noctuid and looper crawl a considerable distance away from the trunk before they settle down under the surface of the ground. Here the change to the pupal stage takes place and the winter rest follows. Earlier tests over a quadrat of 1 m. sides, or a circular area of the same diameter around the trunk, have given a true picture of the presence of the pine moth only. To arrive at a just conception of the population of looper and noctuid a rectangular space of 5 m. by 1 m. has to be marked off, enclosing two trees, one near each end. Figure 2 shows the comparison between the earlier and the more recent tests and the suitability of the latter with regard to the looper and the noctuid.

Again, with the nun moth it is advisable to refrain from the obsolete method of counting the clusters and eggs, for this test does not give accurate results; the eggs are so minute as to escape notice in the majority of cases. It is more satisfactory to examine the chrysalis and ascertain its sex and the extent of its reproductive power.

Before chemical methods were introduced on a considerable scale, attempts were made to fight the outbreak of an insect plague by raking the surface of plantations after the time at which the caterpillars became pupae (in the case of looper and noctuid); by collecting the moths (in the case of the nun moth); and by placing a ring of tar round the trees attacked by the pine moth. All these methods have been used on a grand scale and



Sample plots. FIGURE 2

A. Old methods for pine looper, pine noctuid and pine moth (Dendrolinus).
B. New method for pine looper and pine noctuid.
● *Tree.*
Approximate area occupied around tree "X" during hibernation of pine looper, pine noctuid.
Approximate area occupied around tree "X" during hibernation of pine moth.

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FIGURE 3 – *Pine forest destroyed by pine looper.*

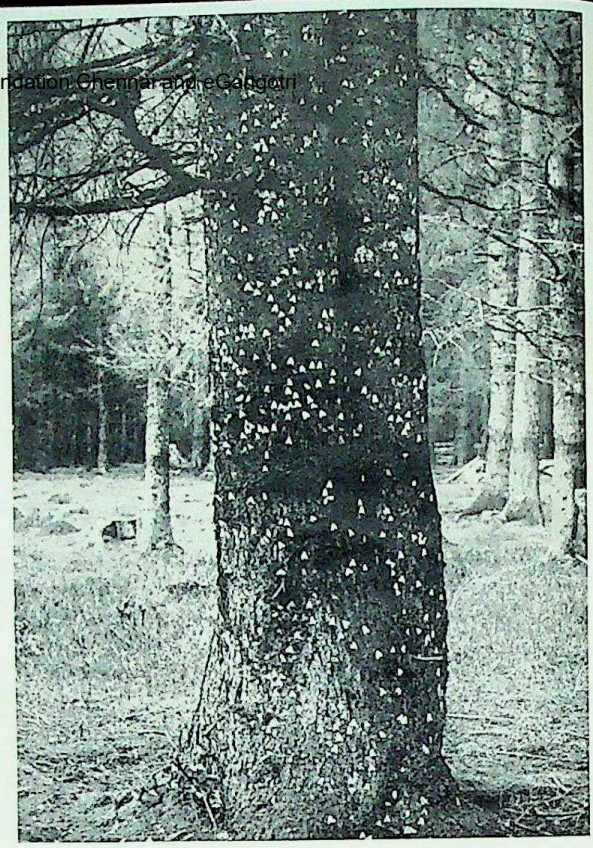

FIGURE 4 – *Nun moth on tree trunk.*
(*From Hoffmann, C. H.*, Nachr. SchädlBekämpf., Leverkusen.)

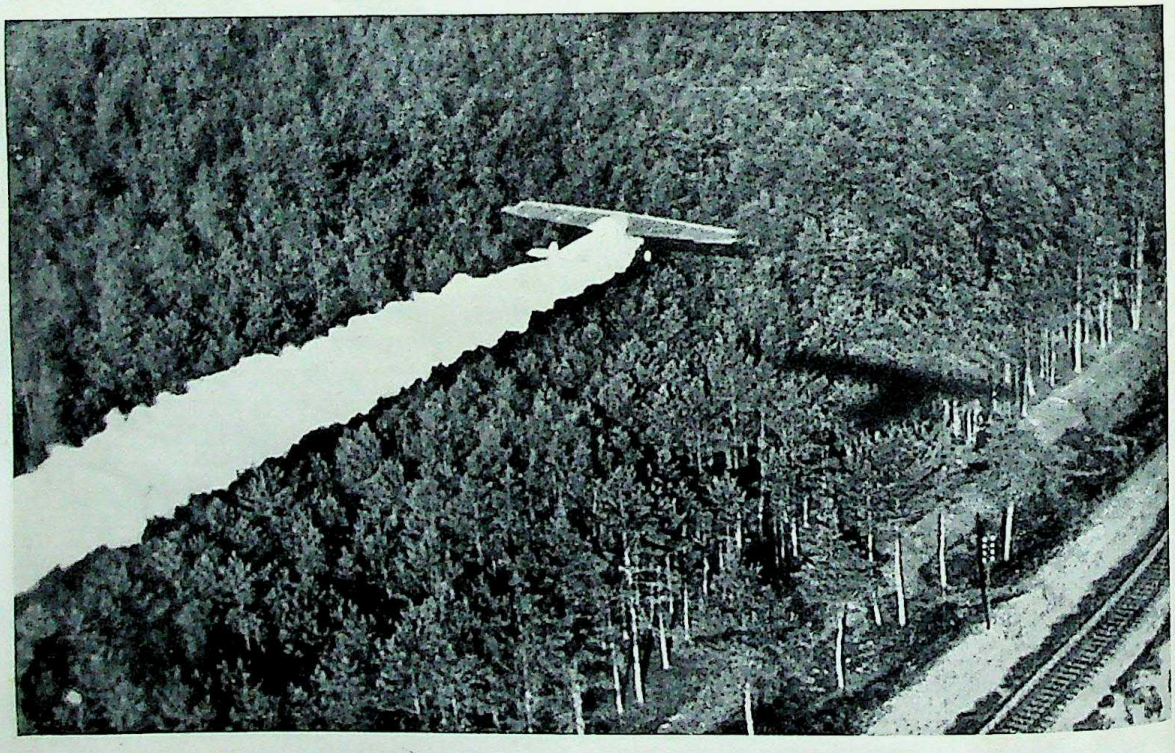

FIGURE 5 – *Aeroplane diffusing poison over a forest attacked by defoliating caterpillars.*

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(except in the use of tar against the pine moth) 0·5 grams per cage. Experts in both chemistry and forestry had therefore to try to find a poison fatal to insects but free from these drawbacks.

with only moderate success. Experts then thought of trying the effect of chemical methods against destructive insects. The first trial was made in 1890 in Bavaria, against the nun moth. The attempt failed, as technical facilities for dusting with powder were lacking.

The first extensive experiment on the use of chemicals to destroy insects was made in 1921 in the U.S.A. by C. R. Neillie and J. S. Houser, acting with the co-operation of the Federal Aviation Experiment Station at McCook Field, Dayton, Ohio [14]. A field of *Catalpa speciosa*, which was attacked by *Ceratomia catalpa*, was dusted from an aeroplane with arsenates of lead (As_2O_3 = 45·06 per cent., PbO = 54·84 per cent.). Thanks to favourable (warm and dry) weather conditions, the test met with complete success. After 48 hours the effect of the poison could be ascertained: 99 per cent. of the caterpillars were dead. This experiment was followed by others in Germany, Poland, and Czechoslovakia against the nun moth, pine looper, and pine noctuid. Up to 1928–29 tests were carried out on a large scale on the Continent, using arsenates of calcium containing up to 70 per cent. of arsenious oxide, As_2O_3. The results, however, left much to be desired, owing to the fact that the efficacy of arsenic, which acts as an internal poison, depends on weather conditions. A further disadvantage of this chemical is the danger of poisoning mammals and birds. 10–12 grams of As_2O_3 will kill a cow,

The first large-scale outdoor experiments with so-called contact dust were made in 1929–30. The effect of these powders is independent of the feeding activities of the caterpillars. To kill them it is only necessary to sprinkle powder on their skin. It causes paralysis and later destruction of the nervous and muscular systems. A great advantage of the use of external poison lies in its independence of weather conditions. Internal poisons are effective only when the caterpillars are actively feeding, and this depends on the weather.

It has been proved that the caterpillars of the pine looper and noctuid abstain for as long as three days from eating the needles sprayed with arsenic. If rain falls during this period the needles are washed clean and the process of dusting has to be repeated. The contact dusts are free from these defects. The first contact dusts were based on veratrin or rotenon, or were derived from the roots of *Derris robusta* (from India). They also contained some sulphate and nicotine. These powders were manufactured at various chemical factories and given different names, e.g. 'forestit' and 'verindal' (Germany), 'choinit' (Poland), and 'polvo' (England) [5]. All these products were used successfully.

In 1931–32 an area of about 150,000 acres attacked by the pine looper in Brandenburg was

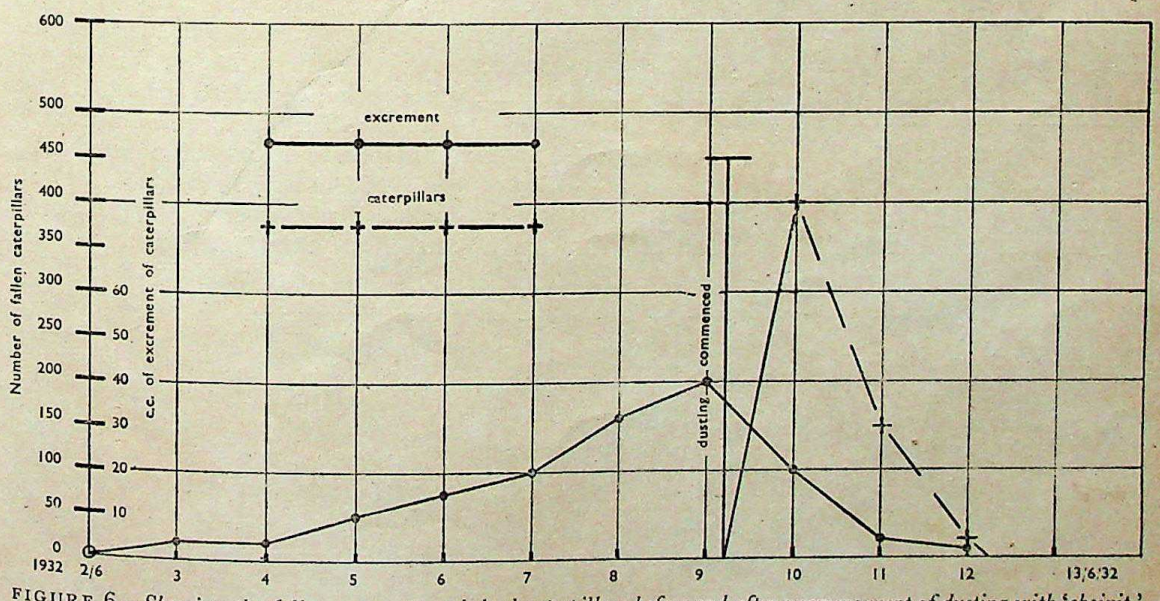

FIGURE 6 – *Showing the fallen excrement and dead caterpillars before and after commencement of dusting with 'choinit.'*

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treated with 'forestit'. Again in 1932 'forestit' and 'choinit' were used in Poland against the pine noctuid, and about 170,000 acres of coniferous plantations were dusted with great success.

Some details of the operation in Poland are of interest. The amount of 'forestit' or 'choinit' used was 50 kgm. per hectare. It was usually applied in the early morning and late afternoon, and only in calm weather was the application continued the whole day. The caterpillars were then between the first and third moults. The attacked stands were dusted only once. To test the effect of the operation, sheets of linen about 2 m. square were laid in various places and the volume of the excreta falling on them before and after dusting was measured; the number of dead caterpillars was also found after the operation. Figures 6 and 7 show the effect of the contact dusts.

In Russia [13] the dusting is started as soon as possible after all the eggs are hatched. The smaller the larvae are, the smaller is the amount of dust required to kill them.

It may be stated that in the Polish woods treated with 'choinit' there were ten healthy pupae in 1 sq. m. of ground, and the number of eggs on a tree-trunk was 1,800–2,200. On the area treated with 'forestit' the corresponding numbers were thirteen pupae and 2,100–2,500 eggs.

About 1 minute after the cloud of poison had touched the tops of the trees, half-dead caterpillars began to fall, and this continued for hours. Neither 'forestit' nor 'choinit' was harmful to mammals or birds. They affected only very slightly the mucous membrane of the human body. As a final result, 98 per cent. of the caterpillars were destroyed, and all the areas of Polish woodlands saved. Contact dusts, based on veratrin, derris, and rotenon, were found to be effective only against hairless caterpillars. They proved less successful against hairy caterpillars such as those of the nun and pine moth, which 'forestit' also completely failed to kill.

A great advance was made in 1932 by the addition of pyrethrum to the contents of the dusts, making them effective against hairy caterpillars. This preparation is produced from the blossoms of certain species of chrysanthemum (*C. marschallii* Aschers, *C. roseum* Adam, and particularly *C. cinerariaefolium* Vis.). The percentage of pyrethrum in the chrysanthemum depends upon the type of the soil and the development of the plant. For a long time there was uncertainty as to the effective elements of preparations of pyrethrum. Rother found three acids which he called persicin, persiretrin, and persitrin. Belesme (1876) found an alkaloid which he called chrysanthemin. Later researches by Staudinger and Ružicka [12] established the existence of two liquids, called by them pyrethrine I and II. They are the esters of the same alcohol, pyrethrolon (methylpentadienyl-cyclopentanolon). Pyrethrine is the pyrethrolon ester of chrysanthemum monocarboxylic acid, pyrethrine II the ester of chrysanthemum dicarboxylic acid. Both esters are poisons affecting the nervous and muscular systems of insects. The efficacy of pyrethrum depends on the age of the caterpillars, but it persists up to the time of the fourth moult. Pyrethrum has the defect that the pyrethrine in it decomposes very easily. This preparation is in general not harmful to man and animals. Occasionally, unpleasant effects may be experienced, but only by persons subject to the so-called 'pyrethrum idiosyncrasy.'

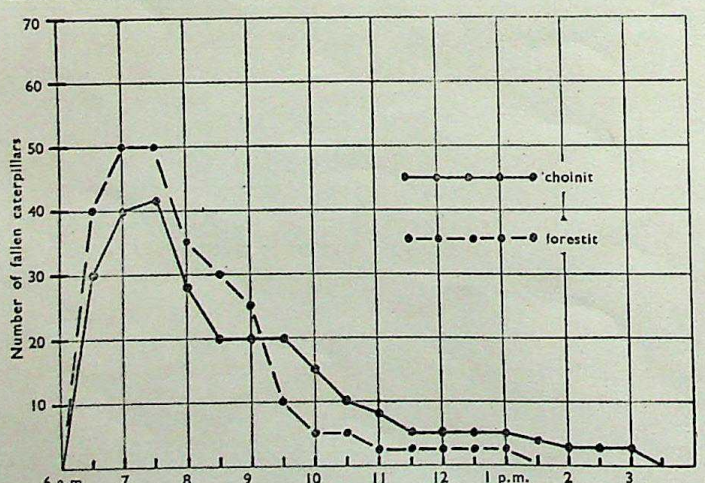

FIGURE 7—*Measured every half-hour after dusting with 'choinit' and 'forestit.'*

Later experiments (1936) were made against the nun moth with contact dusts based on dinitro-*o*-cresol [11]. All hairy caterpillars, even the largest, were destroyed. This preparation, however, has the serious drawback that it is a potent poison if absorbed into the bodies of men and animals. Persons engaged in sprinkling it must wear masks and special clothing and gloves. It also causes signs of burning on young shoots of spruce [4] and on all broad-leaved trees, so that, if a plantation of these is attacked by destructive insects, dinitro-*o*-cresol should not be used to exterminate them.

In recent years, before the outbreak of

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Old and new ideas of gravitation

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E. T. WHITTAKER

In a previous article, Professor Whittaker described the origin, development, and final abandonment of the conception of an aether. The present article, though complete in itself, may be regarded as a sequel to the former one: it tells the story of man's attempts to construct a unitary theory of the external world by discovering relations between gravity, electricity, magnetism, and light. The science of cosmology may help to solve the mystery.

Although gravity was the first of the forces of Nature to be brought within the domain of exact science and represented by a mathematical formula, and although a prodigious amount of highly successful work has been done in the development of the theory, yet the fundamental physical problems connected with it are almost as perplexing today as they have ever been. The Law of Newton, that every particle in the universe attracts every other particle with a force inversely proportional to the square of the distance, provides a method of calculating the effects of gravitational action; and in the course of the eighteenth and nineteenth centuries all the known motions of the heavenly bodies (with one small discrepancy, which was ultimately accounted for by Einstein) were explained satisfactorily by its means. But the Newtonian theory undertook no more than to predict observable behaviour, to answer the question How? It made no attempt to ask What? or Why? or to determine the origin or mode of transmission of the influence, or its connection with the other natural forces.

These wider problems, however, have never been absent from the minds of physicists, and from time to time during the last two centuries efforts have been made to understand the conveyance of gravitational force, to determine whether it is propagated instantaneously or in time, and to discover relations between gravitation, electricity, magnetism, and light, with a view to constructing a *unitary theory* of the external world. From the time of Newton to the discovery of the general theory of relativity in 1915, these investigations were of three main types: first, those which attempted to provide a rationale of the process of transmission by postulating hidden mechanisms and hypothetical aethers; secondly, those which subjected the hypothesis of instantaneous propagation to a critical examination, comparing astronomical observations with the calculated results of various laws involving propagation in time; and, thirdly, purely experimental researches undertaken in the hope of obtaining electrical effects as a consequence of gravitational actions. After the discovery of general relativity, the character of the problem was radically changed and a new line of approach was indicated; the very considerable activity of the last twenty-five years has been inspired for the most part either by new developments in geometry or else by quantum theory. In the present article it is proposed to give some account of the most illuminating contributions to the solution of the mystery.

Of the earlier attempts, we may single out those which tried to find where gravitational energy is located. If two particles, originally at rest at a distance from each other, are free to move under the influence of their mutual attraction, they acquire velocities; that is to say, kinetic energy makes its appearance. This energy must (so the Victorian physicists argued) have been somewhere, in some form, before the motion began: where was it? That this was not a meaningless or hopeless question seemed to be indicated by the fact that the corresponding problem with regard to electricity and magnetism had already been solved. The energy of a system of magnets, corresponding to the forces they exert on each other, was originally found as a mathematical expression in terms of the positions of the magnets. In 1853, however, William Thomson (Lord Kelvin) showed that this expression could be transformed into an integral taken over infinite space; whereupon, by a stroke of genius, he proposed the physical doctrine that the energy was not localized in the magnets, but was distributed over the whole magnetic field. This principle, and a similar one with regard to electric charges, were adopted by Maxwell, and on them was founded the electromagnetic theory of light.

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Could something similar be done for gravitation? Gravitational forces obey the same law (the inverse square of the distance) as electric and magnetic forces, and the lines of gravitational force near two dense bodies are exactly of the same form as the lines of magnetic force near two like poles. The only difference is that, whereas the poles are repelled, the bodies are attracted. Mathematically, there is a change from a plus to a minus sign, which does not affect the possibility of working out the gravitational analogue of Thomson's magnetic theorem, and it was obtained without any difficulty in 1865 by Maxwell; but the minus sign played havoc with the possibility of a physical interpretation, for the energy density was found to be smaller at places where the gravitational force was intense than at places where it was feeble. Now (argued Maxwell) as energy is essentially positive, it is impossible for any part of space to have negative intrinsic energy. Hence the assumption that gravitation arises from the action of the surrounding medium leads to the conclusion that every part of this medium possesses, when undisturbed, an enormous positive intrinsic energy, and that the presence of dense bodies influences the medium so as to diminish this energy wherever there is a resultant attraction. 'As I am unable to understand in what way a medium can possess such properties,' he concluded, 'I cannot go further in this direction in searching for the cause of gravitation.'

The curious sequel of this story is that the concept of negative energy has been introduced and is actually accepted in modern quantum mechanics. An electron in a field of force can make transitions to states in which the energy is negative, and these states play, formally at any rate, an important part in the theory of scattering. Maxwell's difficulty might therefore not seem so serious to us as it did to him; but, as we shall see later, his proposal is now in disfavour for other reasons.

Another question which attracted attention in the nineteenth century was that of the propagation of gravitation: was it instantaneous, or did it occupy a finite time? The only way to settle the matter was to work out mathematically the consequences of various hypotheses and compare them with the results of astronomical observation. (The function of observation is not to furnish hypotheses, but to test them.) One hypothesis was that the force obeyed Newton's Law as to its magnitude, but did not act until it had been transmitted with a finite velocity across the space separating the planet from the sun. This had to be rejected, since it was found that the velocity would have to be at least a million times that of light. The next suggestions were borrowed from electrodynamics. It had been shown in the middle of the century that the ponderomotive forces between electric currents, and the induction of currents, could be explained by assuming the law of force between two electrified particles to consist not only of the ordinary electrostatic term (repulsion according to the inverse square of the distance), but also of a term depending on their velocities[1]. It seemed natural to suggest that the law of gravitation might be of some such character, Newton's Law being merely an approximation valid for the case when the velocity of the bodies is negligible compared with the velocity of propagation of gravitational force. Attempts were made to use this idea in order to account for the secular motion of the perihelion of the planet Mercury, which could not be explained by the simple Newtonian Law; but the results obtained depended so much on *ad hoc* assumptions that they were not felt to be convincing.

Another of the older lines of investigation was experimental in character, and is best represented by the researches described in Faraday's Bakerian Lecture of 1850, *On the Possible Relation of Gravity to Electricity*. The idea inspiring the work was that as two bodies moved towards each other by the force of gravity, electric currents might be developed either in them or in the surrounding matter. Several experiments were performed to test this speculation, but the results were negative. 'They do not,' said Faraday in conclusion, 'shake my strong feeling of the existence of a relation between gravity and electricity, though they give no proof that such a relation exists.'

The age of natural philosophy which began with Newton may be regarded as closing with the death in 1907 of Lord Kelvin, who to the end never relaxed his efforts to solve the great question, Is action at a distance a reality, or is gravitation to be explained, as it was now believed magnetic and electric forces could be, by the action of intervening matter? At one time he had great hopes of an approach by way of hydrodynamics; cyclic irrotational motion, once established through an aperture in a movable solid immersed in a

[1]This (now discarded) was a true 'electron theory,' since it involved only forces between particles, without bringing in a medium, as the later and better-known electron theory of Lorentz did.

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liquid, continues for ever unchanged, however the solid moves; and if there be any other solid at a distance from the first, there will be mutual forces between them. The attempt to bring this property into exact correspondence with gravitational phenomena, by regarding the circulation as the analogue of mass, proved, however, to be impracticable; the true method of replacing action at a distance by contiguous action was yet to come.

It was adumbrated in the last decade of the nineteenth century by Kelvin's friend FitzGerald, in the words: 'Gravity is probably due to a change of structure of the aether, produced by the presence of matter'; but the credit for the successful development of this idea is due wholly to Einstein, who published his theory of general relativity in 1915. The 'aether' of FitzGerald was called by Einstein simply 'space' or 'space-time': and FitzGerald's somewhat vague term 'structure' became with Einstein the more definite and precise 'curvature.' Thus we obtain the central proposition of the Einsteinian theory: 'Gravity is due to a change in the curvature of space-time, produced by the presence of matter.'

What differentiates this from all previous conceptions is that the older physicists had regarded gravity as merely one among many types of natural force—electric, magnetic, etc.—each of which influenced in its own way the motion of material particles. Space, whose properties were set forth in Euclidean geometry, was, so to speak, the stage on which the forces played their parts. But in the new theory, gravity was no longer one of the players but part of the structure of the stage. A gravitational field consisted essentially in a replacement of the Euclidean properties by a much more complicated kind of geometry: space was no longer homogeneous or isotropic. An analogy may be drawn from the game of bowls. Bowling-greens, in the North of England, are not flat, but rise to a slight elevation in the centre. An observer who failed to notice the central elevation would find that a bowl (supposed without bias) always described a path convex towards the centre of the green, and might account for this by postulating a centre of repellent force there. A better-informed observer would attribute the phenomenon to a geometrical feature—the slope. The two explanations correspond respectively to the Newtonian and Einsteinian conceptions of gravity: for Newton it is a force, for Einstein it is a modification of the geometry of space.

The new theory transformed completely the relation between gravity and the other natural forces. Instead of being isolated and unrelated to them, it was now the framework within which they acted, and therefore a potent influence on them all. For example, a ray of light in its passage from a star to the earth would be appreciably deflected if it passed very near the strong gravitational field of the sun; and an electrified body, or a single electron, which is at rest in a varying gravitational field, must emit radiation. Indeed, now that a definite connexion had been set up between electricity and gravitation, the whole of electromagnetic theory needed to be rewritten.

There was, however, one unsatisfactory feature about all this—unsatisfactory, that is to say, from the aesthetic point of view only, for it was not in contradiction with any result of experiment. One of the natural forces, gravity, had been absorbed into geometry; but the others were still forces in the old Newtonian sense. Would the picture of the universe not be more satisfying if they could *all* be absorbed into geometry? Did not Faraday himself, in his theory of lines of electric and magnetic force, initiate some such development? In most of the work done since 1917, the dominant motive has been this idea of the complete geometrization of physics.

Evidently if the geometry in the neighbourhood of any point is to be capable of expressing the whole physical situation there—that is to say, the gravitational field and the electromagnetic field—then it must be a geometry much more elaborate than Euclidean geometry; it must, in fact, be the geometry of a generalized space possessing curvature. What the geometry of a simple type of curved space is like can be understood at once if we think of geometry on the surface of a sphere. On a sphere we can have 'spherical triangles' whose sides are arcs of great circles, and the trigonometry of these triangles is a generalization of plane trigonometry. Now the physicist represents a force by a vector, and therefore if our geometry is to represent physical fields we must have a theory of vectors in generalized space, and of their variation from point to point of the space. In Euclidean geometry the matter is very simple. If U and V are two vectors at the same point P, we can find the vector which is their difference by using the triangle of vectors. But if U is a vector at a point P and V is a vector at a different point Q, and if we want to find the vector which is the difference of U and V, it is

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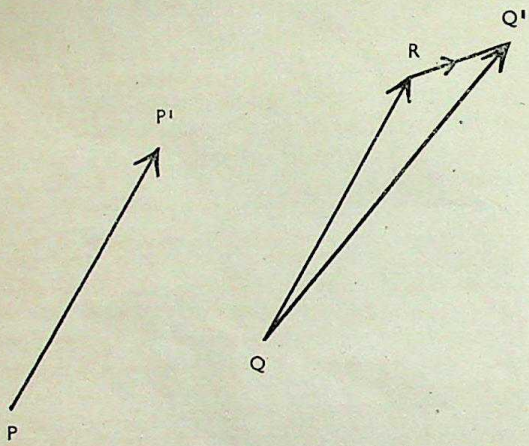
necessary (in principle) first to transfer U parallel to itself from the point P to the point Q, and then to find the difference of the two vectors at Q. Thus a process of transporting a direction parallel to itself, or *parallel transport*, is necessary for finding the difference of vectors at different points, and hence for the spatial differentiation of vectors: and this statement is true also in generalized space.

Let us, then, think of two points P and Q on the surface of the earth, regarded as a sphere; let U be a direction in the surface at P, and let V be a direction at Q. The directions U and V of course cannot (unless P happens to be the antipodes of Q) be parallel in the ordinary



Let PP¹, QQ¹ represent vectors. To find their difference, we must transfer the vector PP¹ to the position QR by parallel transport. The required difference is then RQ¹.

Euclidean sense, i.e. parallel in the three-dimensional space in which the earth is immersed; but a new kind of parallelism can be defined, and that in many different ways. We might, for instance, say that V is derived by parallel transport from U if V and U have the same compass-bearing; so that, e.g., the north-east direction at one place on the earth's surface would be said to be parallel to the north-east direction at any other place.

There are now two different kinds of curve on the earth's surface which may be regarded as analogous to the straight line in the Euclidean plane. If we define a straight line by the property that it is the shortest distance between two points, then its analogue on the earth is a great circle, since this gives the shortest distance between two points on the spherical surface. But if we define a straight line by the property that it preserves the same direction along its whole length, or, more precisely, that its successive elements are derived from each other by parallel transport, then its analogue on the earth is the track of a ship whose compass-bearing is constant throughout her voyage; this is the curve called a *loxodrome*. The existence of the two families of curves, the great circles and the loxodromes, may be assimilated to the fact that if an electrostatic and a gravitational field coexist, the lines of electric force and the lines of gravitational force are two families of curves in space, and this rough analogy may serve to suggest how different physical phenomena may be represented simultaneously in terms of geometrical conceptions.

The geometry which is actually used in the modern theory may be said to regard space as formed of a great number of small pieces cemented together, so to speak, by a parallel transport; it is called *affine geometry*. In the latest memoir on the subject, which was published in the summer of 1943, Professor Schrödinger has shown that a very simple and natural assumption regarding the nature of the Lagrangian is sufficient to produce from straightforward affine geometry the complete system of the differential equations of the combined gravitational and electromagnetic fields. This is the closest approach yet made to realizing Faraday's dream of a unification of the forces of Nature.

That the mystery of gravitation will be completely and finally solved along these lines is, however, unlikely: for in recent years the rapidly developing science of cosmology has brought to light fresh aspects of it which seem to call for radically new treatment. Researches on the expanding universe, on the generation of the energy which is radiated by the stars, and on the dynamics of star-clusters, have all contributed to furnish tolerably concordant estimates of the age of the cosmos; and modern physical theory has to adapt itself to the conception of the Creation. In certain cosmological theories, notably that developed by Professor E. A. Milne since 1933 and that proposed by Professor Dirac in 1937, this is of dominating importance; both these distinguished investigators hold that the laws of nature may be expected to involve the *epoch*, i.e. the interval which has elapsed since the beginning of time: and in particular, that the constant of gravitation, as measured by us, has a value which belongs to the age we live in, but which it did not have a thousand million years ago. This suggests that the attack on the gravitational problem should be begun from the cosmological end: as is, in fact, the tendency of some recent researches.

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Book reviews

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TECHNIQUE OF SCANNING GENERATORS

Time Bases (Scanning Generators): their Design and Development, *by O. S. Puckle. Pp. xii* + 204. *Chapman & Hall Limited, London.* 1943. 16*s. net.*

This excellent monograph deals with all the more important electronic devices for producing the time-axis in cathode-ray oscillographs, television receivers, engine indicators, etc. It outlines the historical development, and provides an introduction to the fundamental principles of modern technique; with this knowledge a student should be well able not only to apply it to any particular purpose but also to understand easily all new developments and descriptions of inventions. The value of the work is much enhanced by a series of seven appendices (nearly one-third of the whole) describing the sealed-off low-voltage cathode-ray tube and the effects of time constants and other valve and circuit parameters. Numerous footnote references to papers, a useful bibliography, and an adequate index are provided. W.J.

DICTIONARY OF ORGANIC COMPOUNDS

Dictionary of Organic Compounds, Volume I, *edited by I. M. Heilbron and H. M. Bunbury. Pp. xvi* + 1072. *Eyre & Spottiswoode Limited, London. New, revised, and enlarged edition,* 1943. £6 6*s. net.*

With Beilstein's *Handbuch* becoming increasingly out of date, publication of a revised edition of the *Dictionary of Organic Compounds*, containing literature references as late as 1941–42, is particularly welcome. Revision of volume I has been extensive. Inclusion of many new compounds, most notably in recently investigated fields of natural products, has resulted in the enlargement of the volume by 366 pages. Generous increase in the number of cross-references, and inclusion of references to 'Organic Syntheses' and to abstracts, in the case of recent patent literature, enhance the value of the volume.

It is a little difficult to appreciate the principle governing the revision of literature references. Frequently many new derivatives are included without any new references being appended; compounds, now included for the first time, sometimes carry only very early references. Relatively little revision of physical data, such as the dissociation constants of acids and bases, seems to have been effected, although many additions to such data have recently appeared. The plan of collecting all references together at the end of an article, without indicating to which specific derivative or property they refer (especially, for example, when *dl-*, *d-*, and *l-* forms exist), somewhat detracts from their value.

These, however, are relatively minor criticisms, and the editors and their collaborators are to be congratulated on the compilation of such a useful and well-selected collection of information in a relatively small compass.

J.W.B.

THE CHEMISTRY AND USES OF STARCH

Starch and its Derivatives, *by J. A. Radley. Pp. xii* + 558. *Chapman & Hall Limited, London. Second edition, revised,* 1943. 36*s. net.*

Although this book is one of a series of monographs on applied chemistry, the description of industrial uses of starch constitutes not more than half of it, the rest of the text being devoted to an attempt to cope with the gigantic mass of literature on what may be called the pure chemistry of starch. The author doubtless hoped thereby to strike a more even balance between pure and applied than was attained in the first edition, in which the technical aspect predominated.

The applied sections in the new edition have been revised, and extended by the incorporation of additional material. They now provide a source of information, much of which is not otherwise readily accessible, of the greatest value not only to technical chemists concerned with the manufacture or the utilization of starch, but also to chemists who are not specialists in these fields but who are anxious to keep abreast of industrial progress.

The sections of the book which deal with the structure and properties of starch represent a laudable attempt to bring some sort of order out of the chaos of contradictory data which has accumulated in the course of a century. This is a herculean task and cannot be done in the space available. These sections become, for the most part, merely compilations of names and views—particularly views—which often are mutually irreconcilable. Compilations of this kind have, of course, their usefulness, and chemists will be grateful to Mr Radley for the diligence which has collected together so many references. Nevertheless, one feels that a monograph is not intended to be an uncritical account of as many hypotheses as may be crowded into an allotted number of pages. One would have preferred to see the author take a stand on the thesis of his own interpretations and not simply to record what *A* thought in 1840 cheek by jowl with *B*'s opinion in 1940 and leave it at that. In one chapter, for instance, the author contrives in fifteen pages of script to refer to more than 200 original papers. Such compression clearly precludes any critical assessment of the relative merit of the work or the workers mentioned.

GUIDE TO THE FUNGI

A Dictionary of the Fungi, *by G. C. Ainsworth and G. R. Bisby. Pp. vii* + 359, *with* 10 *Plates. The Imperial Mycological Institute, Kew, Surrey.* 1943. 20*s. net.*

This book provides a list of all the generic names of fungi (with synonyms) in use up to the end of 1939, with interesting information about many of the genera and a glossary of terms used in mycology and plant pathology. It will undoubtedly be very useful to all students of the fungi, a group of organisms of bewildering variety. Included in the dictionary are references to penicillin, ergot, edible and poisonous fungi, fairy-rings, etc., that even the man in the street has heard of. More information might well have been given about some of the genera, and in this respect the book compares not too favourably with Willis's *Dictionary of the Flowering Plants and Ferns*, on which it has been partly modelled. Above all, a dictionary should be complete, and it is the more regrettable that names given to fungi since 1939 are not included in that they can be found elsewhere.

This dictionary is written chiefly in Basic English. However great the merits of Basic for certain purposes, one can see no possible advantage in its use here sufficient to compensate for circumlocution and a certain lack of precision. In a scientific treatise it is strange to read 'kept from taking place' instead of 'prevented.' F. T. BROOKS

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THE PLANTS OF SANTO DOMINGO

Catalogus Florae Domingensis (Catálogo de la Flora Dominicana). Parte I: Spermatophyta, *by R. M. Moscosco. Pp. xlviii + 732. New York, published for the University of Santo Domingo.* 1943. *N.p.*

Santo Domingo or Española (Hispaniola) is the most central and second largest of the Greater Antilles. The island is mountainous, four mountain groups being recognized, and the highest summits exceed 3,000 m. The rocks and soils are very diversified and the climate is hot and humid. Such physical conditions are favourable to the development of a rich flora and vegetation.

The Director of the Instituto Botánico (R. M. Moscosco), whose *Introducción* is dated September 1938 from Santiago, R.D., and January 1942 from New York, has published what would appear to be a very complete list of all the species of seed-bearing plants known to occur in the island, both in Haiti and the República Dominicana. The list is correctly described in the title as a Catalogus (Catálogo) and not as a Flora, for it contains only names, localities of species ranges within the island, habitat notes, and occasionally brief references to native names and habitats. There are no keys, descriptions, or figures of the plants recorded, which include cultivated as well as native species. The sequence of families is that of Engler's system. The format is excellent and there are adequate indices to Latin and vernacular names. The work should prove of value to all students of New World tropical floras.

W. B. TURRILL

INORGANIC MALNUTRITION IN PLANTS

The Diagnosis of Mineral Deficiencies in Plants by Visual Symptoms: A Colour Atlas and Guide, *by T. Wallace. Pp. vi + 116, with numerous coloured illustrations. H.M. Stationery Office, London.* 1943. 10*s. net.*

War-time cropping and the vital need for obtaining as much food as possible from the land have emphasized the importance of recognizing signs of faulty nutrition at an early stage in the growth of crops. Dr Wallace gives an excellent summary of essential points in the nutrition of plants and discusses the capacity of soils to supply the mineral nutrients, including trace elements, which are necessary for their proper development. After a review of methods of determining mineral deficiencies in crops, he gives details of the visual method of diagnosis in the field, including the use of selected indicator plants. The special feature of the book, however, is the valuable series of colour photographs which will assist greatly in recognizing the symptoms in both agricultural and horticultural crops. Following diagnosis by the rapid visual method, it is often possible to save a failing crop, for instance by timely spraying.

The book will serve as a most valuable guide, particularly for technical officers and advisers.

W.G.O.

MEDICAL APPLICATIONS OF SPECTROPHOTOMETRY

Spectrophotometry in Medicine, *by Ludwig Heilmeyer; translated by A. Jordan and T. L. Tippell. Pp. xiv + 280. Adam Hilger Limited, London.* 1943. 30*s. net.*

The publishers of this book have a reputation second to none in the world as manufacturers of optical instruments for spectroscopy and polarimetry. It is, perhaps, less well known that they are also responsible for publishing certain excellent monographs dealing with the principles of using such optical instruments and also with their application in various branches of science. It is to be regretted that this book will do nothing to increase their reputation as publishers. It is a translation of a monograph published in Germany in 1932—before, it is true, German science began rapidly to slide down the slippery totalitarian path. The use of spectrophotometric methods for diagnostic purposes in medicine may conceivably have made no progress in Germany during the last eleven years. They have been extensively developed during that period elsewhere, particularly in the United States. It is difficult, therefore, to conceive the object of publishing a translation of this book that was not at the same time a thorough revision, bringing all methods into line with current practice based upon the most recent advances. Detailed technical criticism would require more space than is available on the present occasion; all that can with propriety be said is that the book, at the published price of 30s., is poor value indeed, particularly when compared with the excellent monograph by Dr Morton, reviewed in the April 1943 number of ENDEAVOUR. Not only was Dr Morton's book a lucid exposition of a subject in which he himself is a practical expert, it was also a complete revision of the first edition, which appeared as recently as 1935. This revision was found necessary after seven years because of advances that are in no way confined to the application of spectroscopy in the vitamin and hormone field. Similar advances have been made in the spectroscopic study of haemoglobin and its derivatives and breakdown products and of other blood and urinary pigments; the translation of Heilmeyer's book takes no account of these, and the six-page supplement on recent apparatus, with special reference to that manufactured by Messrs Adam Hilger Limited, is quite inadequate to make this book of theoretical interest or practical value.

A. L. BACHARACH

'J.J.'

The Life of Sir J. J. Thomson, O.M., *by Lord Rayleigh. Pp. x + 299, with 9 illustrations. Cambridge University Press, London.* 1942. 18*s. net.*

In an appendix to this book, between three and four pages are occupied by a list of the distinctions conferred upon Thomson. But thousands of Cambridge men, and others, remember him with affection as the unassuming and friendly 'J.J.,' never too busy as Cavendish Professor of Physics to give a word of help or advice, or as Master of Trinity to take a personal interest in every College activity. The main features of his classical contributions to atomic physics are universally known. Lord Rayleigh, who—as a distinguished physicist himself and an intimate friend of Thomson—was doubly qualified for the task, has written a biography in which Thomson's scientific work is described as simply as possible and shown in its relation with the work of his pupils. The human side of the story is by no means neglected, and Lord Rayleigh's narrative leaves us with a clear and illuminating picture of one of the most notable figures of recent times. Though, in the words of Sir William Bragg, Thomson, 'more than any man, was responsible for the fundamental change in outlook which distinguishes the physics of this century from that of the last,' he never lost his unaffected modesty and genuinely desired to be regarded as an ordinary plain man.

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ENDEAVOUR
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Natural and mechanical locomotion

One of the characteristic features of the last half-century has been the enormous development in the means and pace of locomotion. A new medium—the air—has been conquered, and the surface mastery of the oceans has been supplemented by the successful elaboration of sub-aqueous navigation. There are now very few conditions under which man is dependent solely on his own muscles for effective transport. It is significant, however, that the aeroplane and submarine, as well as other locomotory inventions, were either inspired by, or based on, principles already well established in the animal world; and it is therefore of interest to compare the results of man's mechanical genius with the products of Nature's own design.

Much work has in fact been carried out during the last few years upon the locomotory activities of animals, and some of the results deserve to be better known. Apart from its intrinsic interest, progress in our knowledge of the way in which animals move may from time to time provide conclusions of real value and enlightenment to the designer of physical machines. A case in point emerges from an analysis of the mechanism of movement of a typical aquatic animal such as a fish or a dolphin. From a combination of cinematographic and wind-tunnel observations the principles whereby such animals propel themselves through the water and maintain a steady line of movement are known with considerable accuracy. It is possible, therefore, to make at least an approximate comparison of the performance of, say, a dolphin with that of a submarine or torpedo. The resulting data prove to be of very wide general interest.

The maximum under-water speed of a modern submarine is, of course, known to comparatively few people, but it is certainly a great deal less than that of a dolphin. Estimates of the sustained speed attained by the latter have occasionally been exaggerated, but well-authenticated evidence shows that a specimen six feet in length can maintain a minimum speed of 20 knots for long periods of time without showing signs of fatigue. To drive a full-scale rigid model through water at this speed requires about $2\frac{1}{2}$ h.p.; and since the total weight of the muscles operating the body of the dolphin is about 33 lb. it would appear that the horse-power per pound of muscle is roughly 0·07. Now the corresponding figure for the muscles of a very highly trained athlete or dog never exceeds about 0·01, even if the output of work is restricted to a period of time far shorter than that taken in the case of the dolphin. Hence it must be concluded either that the muscles of a dolphin are some seven times as efficient as those of other mammals, or that the resistance of the water to the movement of the dolphin is very much less than to the movement of the rigid model.

The first alternative seems highly improbable, for it would imply the use of an abnormally large quantity of oxygen and the dissipation of heat at an extremely rapid rate through a thick layer of fat. If, on the other hand, it is assumed that the dolphin develops a normal mammalian horse-power per pound of muscle, its total available output would be 0·3 h.p.; and this would suffice to drive the animal through the water at 20 knots if the resistance were about one-tenth of that encountered by the rigid model. This low level of resistance would be possible only if the flow of water past the body were perfectly smooth and did not involve a wastage of energy comparable with that due to the large eddies characteristic of the flow past the rigid surface of the model. During the animal's motion, the whole surface of the body is constantly being deformed by the undulatory movements which form an essential part of the locomotory mechanism, and the

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possibility that these undulations may be the means by which eddy formation is eliminated is suggested by recent observations on the flow of water past the bodies of fish. Similarly indicative is the fact that when a dolphin is swimming in a medium which is itself phosphorescent only when turbulent, the outline of the body is very sharply defined as a phosphorescent surface: there is no evidence of large eddies. If this preliminary work is substantiated by further research, the possibility of endowing a submarine or torpedo with an actively undulating surface will provide an interesting field for speculation and engineering skill.

In the range of aerial movement, the comparison between a bird or an insect and an aeroplane is obvious. So long as a bird is gliding, the whole animal is strictly comparable with a glider aeroplane—with one important difference. In the case of the glider, the aerofoils and rudders are rigid, whereas in the bird the all-important feathers are highly flexible. This renders the wing virtually unstallable and endows the bird with very remarkable powers of manœuvre. When flying under power, the action of a bird's wing is highly complex, for it represents both the wing and the airscrew of an aeroplane combined into a single unit. Further, whereas the speed of flow from the airscrew is more or less steady, the flow past the oscillating wings of a bird is extremely variable and complex. At the beginning and end of each half-cycle of oscillation the wing is at rest, but at intermediate positions the velocity is surprisingly high. For example, the rate of movement of the tip of a pigeon's wing during quite slow and deliberate flight is of the order of 60 m.p.h., and it reaches this speed within one-twentieth of a second after starting from rest.

In order to observe such movements adequately, spark photography is essential; but by the use of suitable apparatus a relatively complete picture has now become available of the whole cycle of wing-beats. This makes it clear that the flexibility of the individual feathers, and of the wing as a whole, plays a very vital role in the maintenance of steady flight. The general impression derived from the work suggests that the mechanism of bird flight would be appropriate only for relatively small animals travelling at speeds not substantially higher than 60 m.p.h. It is, however, associated with a power of manœuvre far in excess of that of any aeroplane.

To glance briefly at another natural and mechanical parallel, it may be remarked that the movements of the snail and of the caterpillar tractor are based on closely similar principles. In both cases the essential feature of movement is the maintenance of a relatively large and stationary bearing surface on the ground. The way in which this condition is fulfilled in the snail has recently been studied. It provides an interesting example of Nature's achievement of the same end as man, although the individual components of the machine are entirely different in the two cases.

To some extent, Nature is more versatile than man in the use of fundamental principles. For instance, she not only effectively employs jointed levers in the limbs of most vertebrates but, in the case of the gliding of a snake, uses a principle so far completely neglected by the human inventor. The progression of snakes was to Solomon one of the three most inscrutable phenomena, but it is in fact fairly simple. It depends upon the ability of the animal to press the sides of its body into contact with three or more external objects and to adjust its shape to such a form that there is always a backward pressure against the points of contact.

In general it may be said that Nature's mechanisms differ from those of man in two fundamental characters. Firstly, Nature almost invariably employs flexible rather than rigid material for the construction of component parts. Secondly, she does not employ the principle of the wheel and axle. Relatively high speed movements in an animal depend on the ability of muscles to produce extremely rapid acceleration of the various oscillating parts, and the dangerous strains involved must be guarded against by safety devices built up from flexible elements. Except in under-water conditions, animals cannot compete with man's inventions as far as speed is concerned—but in respect to powers of manœuvre Nature is always an easy winner.

Contributions and correspondence should be sent to the editor: E. J. Holmyard, M.A., M.Sc., D.Litt., F.I.C., Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1. Scientists engaged in research of an interesting or important character are invited to send short notes on work in progress and results obtained.

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Chemistry of the Australian Bush

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JOHN READ

Australia, 'the land of the eucalypt and the kangaroo,' has a flora that is at once strange and unique. Very much of the vegetation consists of members of the natural family *Myrtaceae*, of which Europe possesses only one indigenous species. Professor Read discusses some of the interesting botanical, phytochemical, and chemical problems presented by Australian plant life, and pays tribute to the pioneer work of R. T. Baker and H. G. Smith.

A STRANGE FLORA

From its discovery onwards, Australia has appealed to the outside world as the habitat of a strange flora and fauna. Multitudes who have never been remotely 'within coo-ee' of the great southern continent picture it to themselves as the land of the eucalypt and the kangaroo. A great deal lies behind this popular conception of Australia. The eucalypt and the kangaroo are vivid symbols of a unique flora and fauna; more than that, in some degree they are typical survivals into the present age of an order of living things inherited from a remote epoch, and elsewhere obsolete or non-existent. This ancient order, seemingly unchangeable or developing in a unique manner in its isolated Australian environment, has stamped its impress as deeply upon the indigenous plant products of Australia as upon visible characters of the parent flora.

Captain William Dampier, in 1688, mistook the eucalypts of north-western Australia for 'Dragon-trees,' and later Europeans to reach Australia could not fail to notice the strange appearance of the trees, shrubs, and flowers which confronted them. The first detailed record of such an impression is of great historic interest, for it may be traced back to Captain James Cook's original landing from his barque *Endeavour* on the eastern coast of Australia, on 20th April, 1770. On Sunday, 6th May, Cook wrote in his journal (now in the Mitchell Library, Sydney): 'The great quantity of this sort of fish found in this place occasioned my giving it the name of *Stingray Harbour*.' Before the *Endeavour* reached Batavia, however, he had changed the entry to: 'The great quantity of New Plants, etc., Mr. Banks and Dr. Solander collected in this place occasioned my giving it the name of [*Botanist* corrected to] *Botany Bay*.'

Mr (later Sir Joseph) Banks described (3rd May) how he carried ashore at Botany Bay 'all the drying paper, nearly 200 quires, of which the larger part was full, and spreading them upon a sail in the sun, kept them in this manner exposed the whole day.' In the following month his specimens were soaked with sea-water as a result of the historic accident near the Endeavour River; but they are still extant in good condition —many of them were presented by the Trustees of the British Museum to the National Herbarium at Sydney in 1904.

The strangeness of the indigenous flora of Australia to the European visitor arises from the fact that so much of this vegetation belongs to the *Myrtaceae*, a large family of which Europe claims only a single species in the sweet-scented myrtle of the poets (*Myrtus communis*). In Australia, there are more than eight hundred species of *Myrtaceae*, a number exceeded only by the much less conspicuous *Leguminosae*, with some thirteen hundred species. Of the forty-five genera of *Myrtaceae* represented in Australia, the most important is *Eucalyptus* [14]. This genus is a highly specialized form of myrtaceous plants, developed in great profusion probably after the separation of Australia from the great tropical lands and adapted to its xerophilous and more barren environment [14]. Among other myrtaceous genera occurring in Australia are *Myrtus*, *Eugenia*, *Angophora*, *Backhousia*, *Melaleuca*, *Leptospermum*, and *Darwinia*. The last three of these genera are shrubby, the others, like *Eucalyptus*, mainly trees. All of them except *Myrtus* and *Eugenia*, which bear fleshy berries, have dry fruits. Myrtaceous genera with dry fruits are chiefly Australian, but a few representatives are found in New Guinea, Celebes, New Caledonia with neighbouring islands, and New Zealand. The shape and size of the fruits are important in the identification of *Eucalyptus* species. The indigenous occurrence of the genus *Eucalyptus* is mainly confined to Australia, New Guinea, and Celebes, but suitable

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species are now cultivated extensively in many other countries, ranging from New Zealand to California, South Africa, and the Mediterranean region, mainly as timber trees of exceptionally rapid growth, and for their beneficial effect when planted in marshy land. For example, near Rotorua, New Zealand, *E. oreades* readily grows to a height of 120 ft. in thirty years.

THE EUCALYPTUS OIL INDUSTRY

Although the biochemical features of living organisms are much less obvious than their morphology, yet the earliest settlers in Australia quickly became aware of the richness of the trees and shrubs of the 'Bush' in fragrant oils and also in resinous exudations. The latter products, so common among eucalypts, were mistakenly called 'gums,' and the name was transferred to the trees themselves. The timbers of numerous species of *Eucalyptus* are deservedly held in much esteem [1]; but chemically the greatest interest of this premier genus of Australia lies in its essential oils.

These oils are secreted in minute, semi-transparent leaf-glands, which may be seen when a leaf is held up to the light; sometimes, too, a similar oil is found in the bark and wood. Essential, or essence-like, oils possess fragrant odours, as the name indicates. They are more mobile and more volatile than the 'fixed' plant oils, such as linseed, cotton-seed, coco-nut, and olive oils; unlike these oils, they are not of a fatty nature, and are unassimilable. Their high inflammability is largely responsible for the fierceness of Australian bush fires. Besides *Eucalyptus*, the other myrtaceous genera already mentioned are also lavish sources of essential oils, and so are many other native Australian plants belonging to the *Coniferae*, *Rutaceae*, *Labiatae*, and other families. Thus the essential oil industry, which grew up in Australia around the eucalypts, has gradually extended to embrace many species in other genera and families of indigenous plants.

Of all such oils, those of the eucalypts are by far the commonest and the most important. The story of the first distillation of an Australian essential oil is bound up with Dr John White, Surgeon-General to the First Settlement. He went out with Governor Phillip, who reached Botany Bay with his fleet of marines, officials, and convicts on 20th January, 1788. The voyage from England, by way of Rio de Janeiro and the Cape of Good Hope, took more than eight months, and is described with much interesting detail in White's *Journal*, dated from Sydney Cove, Port Jackson, New South Wales, 18th November, 1788 [9] [15].

Soon after the incipient colony had moved from Botany Bay to Port Jackson, White ran out of oil of peppermint, which was much prized in those days as a specific for 'gouty and cholicky pains' and 'disorders arising from wind.' The surgeon-general and his assistant, Considen, found an efficient substitute in the oil distilled from the leaves of a tree growing on the shores of Port Jackson. The statement in an Appendix to White's *Journal* [15] runs as follows:

> The name of Peppermint Tree has been given to this plant by Mr. WHITE on account of the very great resemblance between the essential oil drawn from its leaves and that obtained from the Peppermint (*Mentha piperita*) which grows in England. This oil was found by Mr. WHITE to be much more efficacious in removing all cholicky complaints than that of the English Peppermint, which he attributes to its being less pungent and more aromatic.

The Appendix to White's *Journal*, containing an illustrated account of the flora and fauna of the new land, includes a drawing entitled 'The Peppermint Tree.' This species is now known as *Eucalyptus piperita*, or the Sydney Peppermint, and is common around Sydney and in the Blue Mountains of New South Wales.

It is often supposed that 'eucalyptus oil' is a standard material consisting mainly or wholly of eucalyptole, otherwise known as cineole, the odour of which is disseminated so freely from handkerchiefs during epidemics of colds or influenza. The term 'eucalyptus oil,' however, is a vague one with no precise meaning. In fact, each species of *Eucalyptus*—of which more than three hundred[1] are known—has its own distinctive oil, and each oil is a complex mixture of constituents. White's original eucalyptus oil, as we have seen, had an odour of peppermint and not of eucalyptole. The odours of eucalyptus oils range indeed over a wide gamut, including turpentine, eucalyptole, peppermint, lemon, and geranium among its dominant notes.

These oils and their numerous ingredients have been applied in many ways. The original uses of eucalyptus oils were medicinal. For such purposes the oil of *E. globulus*, or Blue Gum,

[1] The number of *Eucalyptus* species recognized by different investigators varies over a wide range, up to a maximum of some five hundred. There are also considerable variations in the nomenclature of the genus: for the purposes of this account it has proved simplest to adopt the nomenclature of Baker and Smith [2].

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formerly took first place, but eventually this was replaced by cineole oils of the same general character obtained from species producing higher yields of oil. Thus, the leaves and twigs of *E. globulus* furnish less than 1 per cent. of oil, a yield which is doubled in *E. polybractea* and nearly quadrupled in *E. australiana*. These three oils are rich in cineole, and are used mainly as mild disinfectants or germicides. This useful property is exhibited in different degrees by many other eucalyptus oils, and is not peculiar (as was formerly supposed) to those containing cineole. The first factory for the extraction of eucalyptus oils was started in Victoria by Bosisto in 1854. As the oils from various species became better known, some were found to be of value for perfumery, some for use in special processes such as the 'flotation' process for concentrating ore, and some for the manufacture of fine organic chemicals. Eventually, therefore, the distillation of eucalyptus oils grew into an important Australian industry.

This industry literally has its roots in the Australian bush, and in favourable localities the oil distillers' camps with their batteries of crude stills are a familiar sight. In travelling along a bush track in such a region one may traverse a natural forest of eucalypts of many species. In age, these may range from seedlings a few inches high and a few months old to monarchs of the forest dating back before the days of Captain Cook and the First Settlement. Among them, in a particular district of New South Wales, may be seen gigantic Bloodwoods (*E. corymbosa*), distinguished by their rough scaly bark, of warm red hue, and long dark dribbles of exudation; clean-limbed Peppermints (*E. phellandra*), with narrow leaves and delicately latticed bark; lofty White Stringybarks (*E. eugenioides*), with the characteristic ridged bark, fibrous and intertwining; graceful Gully Ashes (*E. smithii*), grey-limbed with long pendulous leaves; and many others.

Such eucalyptus species are strongly individualistic in appearance. They may be trim eucalypts, with bark persistent on trunk and branch; unkempt eucalypts, with bark partly adherent and partly shed; dishevelled eucalypts, waving long barky tresses in the breeze; stark eucalypts, spreading white arms wide against the cloudless blue of an Australian sky; spotted eucalypts; sombre eucalypts; silvery eucalypts; and eucalypts of still other types, in bewildering variety. Between their boles, in this New South Wales district, a luxuriant scrub grows in profusion: many species of leptospermum, with small sweet-scented leaves; feathery, dark-green wattles; stiff-leaved banksias; slender-stemmed waratahs; soft-petalled flannel flowers, reminiscent of edelweiss—new species at every turn illustrating the richness and strangeness of the bush vegetation in this region of Australia [7].

The ecology of the eucalypts is of great interest. The species differ greatly in kind according to soil, altitude, climate, and other environmental conditions. In the natural distribution of the genus, each region thus possesses a characteristic selection of species adapted to the locality in which they grow. In general, it is unusual to find a eucalyptus forest composed exclusively of one species; for, with the exception of *E. phellandra* and a few other species, the gregariousness of the eucalypt is generic rather than specific. Eucalypts vary in size from small shrubby 'mallees' to giant forms like the noble *E. regnans*, which, in Gippsland, has been known to exceed 300 ft. in height, with a girth of nearly 70 ft. The large trees occur chiefly in regions having a sandy soil poor in mineral constituents, of which they store only a minute amount (0·025 to 0·05 per cent.) in their timber: this peculiarity has been advanced as a prime factor affecting their growth to such great dimensions.

The suitability of a species as a commercial source of oil depends upon the composition and yield of the oil; also, for naturally growing trees, upon the accessibility of the species. The average yield of oil furnished by the mature leaves and terminal branchlets ranges from about 3·5 per cent. in *E. australiana* and *E. phellandra* to 0·06 per cent. in *E. corymbosa*, and dwindles to mere traces in still poorer species. In the harvesting of eucalyptus leaves for distillation, the trees may either be lopped or felled; although felling may appear extravagant, it is often favoured by experienced distillers. When the tree is cut within a foot or two of the ground, a strongly foliaceous 'sucker growth' soon appears, and this may be cut again and again without destroying the reproductive capacity of the tree. The phoenix-like eucalypt conforms to the general motto of the Australian flora, which is '*Resurgam!*' It combines amazing vitality with unusual rapidity of growth in favourable conditions; thus, after the lapse of a couple of years, the decapitated stump may have surpassed the ideal of Dean Swift by producing not merely two, but three, or even four, sturdy stems where only one grew before.

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The scrub of Blue Mallee (*E. polybractea*) in the Wyalong district of New South Wales is sometimes treated still more severely. Mallees are dwarf eucalypts having a bunchy growth of small stems springing from a root-crown. In western New South Wales, and also in South Australia and other regions, mallee eucalypts cover large areas. One of them, *E. oleosa*, stores water in its roots, a beneficent provision which was appreciated by the Australian aborigines. Three mallees in particular yield excellent cineole oils: besides the Blue Mallee of New South Wales, these are *E. odorata* and *E. cneorifolia*, from which the bulk of South Australian eucalyptus oil is distilled; the last-named species occurs chiefly on Kangaroo Island.

In dealing with the Blue Mallee, the distiller flattens and partly uproots the scrub by driving a heavy roller over it, and after the roughly treated vegetation has dried in the strong sun he completes its seeming destruction by burning it off. The bare waste which repels the eye at this juncture seems to lack any germ of life. *Resurgam!* In a short time the irrepressible eucalypt reappears: a pleasing dull blue mantle of *E. polybractea* covers the landscape; and after a twelvemonth the distiller's faith is justified by the sight of a luxuriant growth of mallee rising waist high.

The harvesting of the leaves is simpler from mallees than from trees, but the remaining operations are the same for material from either source. In order to liberate the oil, the leaves are brought into contact with steam: this bursts the oil-glands and causes a slow vaporization of their contents. The crude field-still consists of a cubical iron tank with a capacity of 400 gallons, corresponding to about 800 lb. of material when fitted for open firing. The tightly packed leaves rest upon a grating, below which water is boiled by means of a wood fire beneath the tank. As the steam forces its way up through the mass of leaves it becomes charged with the vaporized oil, and the mixed vapours are condensed during their passage through a water-cooled exit tube. The liquid mixture of water and oil runs down into a receiver which is so constructed as to allow the relatively small layer of oil to be drawn away from the water on which it floats. In the more refined types of distilling plant, steam is generated in an independent boiler and passed under pressure into a series of digesters, these being sometimes sunk into the ground in order to facilitate the handling of the fresh and spent leaves. The procedure now outlined is not restricted to the winning of eucalyptus oils: it may be applied generally in the separation of essential oils from plant materials, provided that the chemical constituents are not damaged by steam.

There are many cineole-bearing species, and the reputation of the cineole oils has suffered in the past owing to occasional confusion in the field. A vernacular name, such as Messmate, may be interpreted in various ways, according to local opinion; hence, many years ago, reliable distillers began to adopt the systematic latinized names. The use of scientific nomenclature 'out back' in the Australian bush may cause surprise; yet—as a 'bushwhacker' once remarked, in somewhat different words—there is nothing inherently difficult in the pronunciation of *Eucalyptus macarthuri*, and the name is decidedly more euphonious than the synonymic 'Camden Woollybutt' or 'Paddy's River Box.' In this and many other respects the bush distiller is eminently adaptable and full of resource. Let us take a backward glance at him in a primitive gunyah near Wingello: he is sitting on a kerosene tin before a packing-case, making shift to answer a business letter. He dips his quill into home-made charcoal ink, and writes in the dim light of a primitive lamp: this, too, has been made on the premises, and it burns the home-distilled oil of *E. macarthuri*. 'Greenhide and stringybark are the backbone of Australia!' he murmurs, gazing at his humble bark roof, as he quotes a saying familiar to the early pioneers to whom he is so closely akin in spirit. He is indeed a virile and picturesque Australian type, full of first-hand knowledge mingled with the lore of the bush.

CHEMICAL CHARACTERISTICS OF EUCALYPTS

It is now time to sketch in the scientific background of the eucalyptus oil industry. The first chemical investigation of such an oil was carried out by Cloëz in 1870: this French chemist obtained an impure specimen of cineole by fractionally distilling the oil of *E. globulus*. Since that time numerous investigators, in Australia and elsewhere, have gradually unfolded the fascinating chemistry of the Australian flora. At the present day, in the genus *Eucalyptus* alone, the essential oils of some two hundred species have been examined chemically.

So interwoven are the relationships in this genus, so refined the specific distinctions, that effective studies could be prosecuted only through the combined efforts of the botanist and the

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organic chemist. Happily such a collaboration was forthcoming. In 1895, H. G. Smith (1852–1924) published, in collaboration with J. H. Maiden, the distinguished Australian botanist, his first original contribution to organic chemistry, in the form of a paper dealing with eucalyptus kinos, or resinous exudations. In the same year, R. T. Baker (1854–1941) became Curator of the Sydney Technological Museum, where he acted also as Economic Botanist; and in 1899 Smith was appointed Assistant Curator and Economic Chemist at the Museum. The two colleagues entered into an enthusiastic collaboration, and from that time until their retirement in 1921 carried out at the Museum a classical series of botanico-chemical investigations on the Australian flora. Baker and Smith were both born in Kent, England, and made their ways separately to Sydney in the early eighties; they were pioneers of scientific investigation in a new country, and it is remarkable that both of them were largely self-educated for their main life-work. Handicapped in various ways, and receiving less scientific recognition and material reward than could have been desired, they were animated by the spirit which inspired Scheele, of whose life and work Smith was a great admirer: 'The elucidation of new phenomena is my sole concern,' wrote Scheele to Gahn in 1774, 'and how happy is the investigator when the final success of his struggles brings joy to his heart.'

The researches of Baker and Smith on the genus *Eucalyptus* were published at Sydney in 1902, with a revision in 1920 [2]. These researches on the essential oils of numerous species, representative of the Australian mainland and of Tasmania, showed that altogether the genus elaborates more than forty distinct chemical constituents of such oils, of which about half owed their first recognition in eucalyptus oils to Smith. Most of these substances are hydrocarbons or oxygenated derivatives belonging to the terpene series, such as pinene, phellandrene, limonene, cineole, piperitone, eudesmol, geraniol, citral, and citronellal; in addition, there are aliphatic and aromatic constituents. Some of them are peculiar to the Australian flora, which also provides the most abundant source of some of the others.

Each oil contains a certain selection of these constituents in fairly definite proportions, and is thus distinctive for the species. The composition of the leaf-oils appears to remain sensibly unchanged in eucalypts cultivated outside their natural Australian habitat [4]. The yields of oil may be increased considerably by cultivation. Baker and Smith concluded that *Eucalyptus* species may be characterized chemically as well as morphologically. More remarkable still, they were sometimes able to discern a chemical distinction between closely related species, or varieties, when no decisive morphological distinction was apparent. For example, they founded the species *E. phellandra* almost wholly on chemical evidence: 'the economic importance of separating this species from *E. australiana*,' they wrote in 1920, 'can be judged from the fact that at the present time the value of the oil of the latter species is more than double that of *E. phellandra*.'

This quotation illustrates the dual significance of Baker and Smith's collaborative researches, in which the latent economic possibilities were no less important than the immediate scientific advances. The full value of *Eucalyptus* oils as sources on a vast scale of many fine organic chemicals gradually became evident. The crude oil of a good cineole-bearing species, such as *E. polybractea* or *E. smithii*, may contain more than 80 per cent. of cineole, which separates readily (especially from the 'first-hour oil' of the distillation) as a glacial crystalline mass when the oil is cooled in an ammonia refrigerator. *E. dives* oil, when fractionally distilled, may yield about 50 per cent. of piperitone and 40 per cent. of phellandrene: thus it becomes a potential source of such related substances as thymol and menthol. The oil of *E. macarthuri*, containing some 75 per cent. of geranyl acetate, together with a little free geraniol, offers an abundant source of this valuable ingredient of perfumes; this oil contains in addition the much rarer eudesmol, a sesquiterpene alcohol. In New Zealand, where this species is valued also for general and farming purposes, it is grown in extensive plantations around Rotorua.

The crude oil of *E. citriodora*, the 'citron-scented gum' of North Queensland, consists almost wholly of citronellal (90 per cent.); and another Queensland species, *E. staigeriana*, yields a lemon-scented oil containing about 16 per cent. of citral. This oil played a part in one of H. G. Smith's most spectacular demonstrations of the value of Australian plant products for everyday purposes [8]. On the occasion of a formal dinner famous in the annals of the Royal Society of New South Wales, Smith smuggled into the menu an alleged sago pudding flavoured with lemon, which, during his after-dinner speech, he divulged to have been

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made under his supervision from the starch of the Burrawang 'Palm' (*Macrozamia spiralis*), flavoured with the leaf-oil of the 'lemon-scented ironbark' (*E. staigeriana*). Fortunately, the effect of this *tour de force* upon the Fellows was more agreeable than the sequel to Basil Valentine's much earlier but fundamentally similar experiment with an antimonial preparation upon the monks of St Peter of Erfurt! [10].

Baker and Smith's generalizations from this joint work are remarkably interesting. They concluded that the oil from any *Eucalyptus* species growing under natural conditions maintains a comparatively constant composition; that each chemical constituent increases in amount through a sequence of species until it reaches a maximum in one or more of them; and that a connexion exists between certain morphological characters, notably the type of venation of the mature lanceolate leaves, and the chemical nature of the oil. A 'feather' venation (as in *E. corymbosa* and *E. calophylla*, the 'red gum' of Western Australia) denotes the presence of pinene and possibly of bornyl acetate (Group I); an intermediate venation (as in *E. globulus*, *E. smithii*, and *E. polybractea*) is a sign of the occurrence of pinene with cineole (Group II); and a 'butterfly-wing' venation (as in *E. piperita* and *E. dives*) points to phellandrene and possibly piperitone or geranyl acetate (Group III).

Thus, a large number of *Eucalyptus* species fall into one of three main groups, of which the chemical characteristics may be deduced from a mere inspection of the leaf-venation [11]. This is a startling conclusion, suggesting *inter alia* a revival of the mediaeval doctrine of signatures [10], according to which 'the president of *Nature*' conveyed valuable information to man by insculping 'notable and marvelous *Figures* upon *Plants* . . . and other inferior *Bodies*.' This idea may be carried still further with certain species. For example, *E. gullicki* and *E. haemastoma*, sometimes found growing side by side, are much alike in the field, being trees of medium size with a smooth, white bark. Both the venation of the leaves and their odour, when crushed, indicate, however, that *E. gullicki* secretes cineole (Group II) and *E. haemastoma* phellandrene (Group III). More than this, the latter species, which is known also as Scribbly Gum, almost always shows insect markings, resembling scribbles, on the bark, while *E. gullicki* is innocent of such markings. *E. punctata* and certain other species exude warty masses of 'eucalyptus manna' from insect punctures in bark and leaves: this curious product consists of a sugar, raffinose.

AN EVOLUTIONARY THEORY

A larger outcome of these phytochemical researches, which embraced the detailed examination of other botanical and chemical features (including the morphology of anthers and cotyledons, the colours of timbers, and the chemical nature of exudations), was Baker and Smith's development of an evolutionary theory, dealing with a geographical and chronological sequence in the genus *Eucalyptus* [2]. There is evidence that the genus may have occurred in Tertiary, or perhaps Cretaceous, times in the northern hemisphere; but Baker and Smith's theory relates only to Australia. According to this theory, the genus perhaps originated in north and north-west Australia, none but the oldest species being found in this region: these belong to Group I, and have 'feather'-veined leaves yielding a maximum of about 0·5 per cent. of a pinene oil. Chemical evolution is held to have accompanied botanical evolution. As the genus spread slowly eastwards and southwards, the evolution of new species was determined by changing conditions of soil and climate, and the pinene-cineole oils of Group II made their appearance. At the end of the evolutionary scale, the most recent species—those of Group III—occur only in south-east Australia and Tasmania. In the passage from the 'feather' to the 'butterfly-wing' venation the angle between the midrib and the lateral veins becomes progressively more acute, and in the last two groups the yield of oil rises to a maximum of about 4·5 per cent., since there is more room for oil-glands between the lateral veins of the last two types than in the 'feather'-veined structure.

The primary type is persistent, some species being common to the western (Perth) and eastern (Sydney) regions, although no representative is known in Victoria (apart from the eastern coastal strip) or Tasmania. Even the most recent species are very old: more than half of the indigenous Tasmanian species are found on the mainland, and it is concluded that these must have been distinct species long before the formation of Bass Strait.

Besides the three main groups of *Eucalyptus* included in this supposed order of evolution, the evolutionary classification takes into account such exceptional species as *E. macarthuri* and *E. citriodora*, in which the chief constituents of the leaf-oil are geranyl acetate and citronellal

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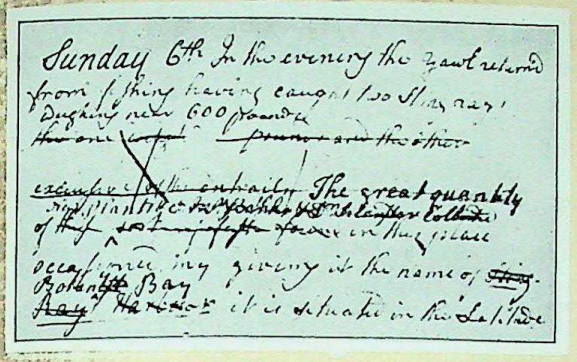
Sunday 6th In the evening the Yawl returned from fishing having caught 130 Skate rays Dogfish weighing about 600 pounds

FIGURE 1 – '*The name of* Botany Bay'*: an entry in Captain Cook's Journal for* 6*th May*, 1770.
(With acknowledgments to the Commonwealth of Australia National Library.)

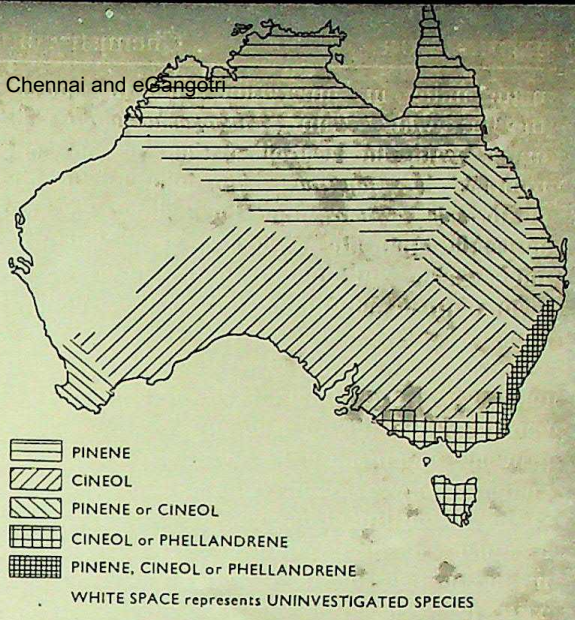

FIGURE 2 – *Phytochemical distribution of* Eucalyptus *in Australia. The map shows approximately the geographical limitation of* Eucalyptus *species according to the main chemical constituents in their oils.*
(R. T. Baker and H. G. Smith [2].)

FIGURE 3 – *Richard Thomas Baker* (1854–1941).

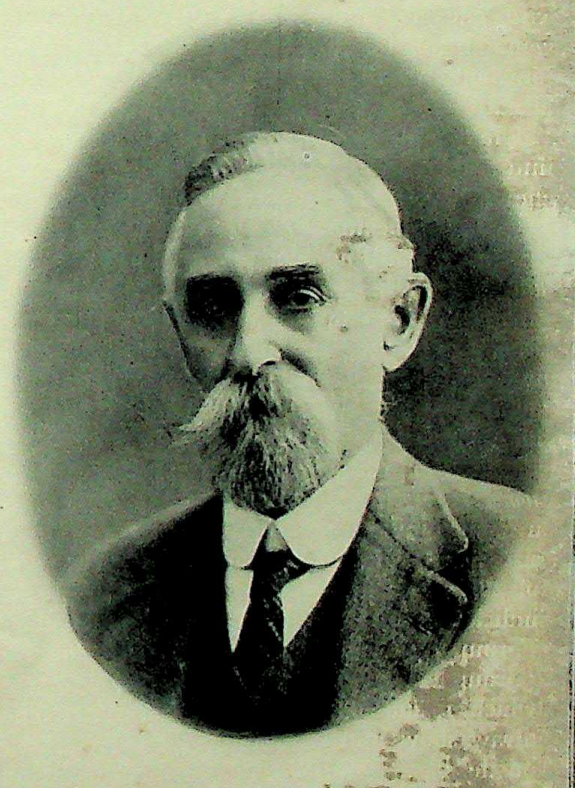

FIGURE 4 – *Henry George Smith* (1852–1924).

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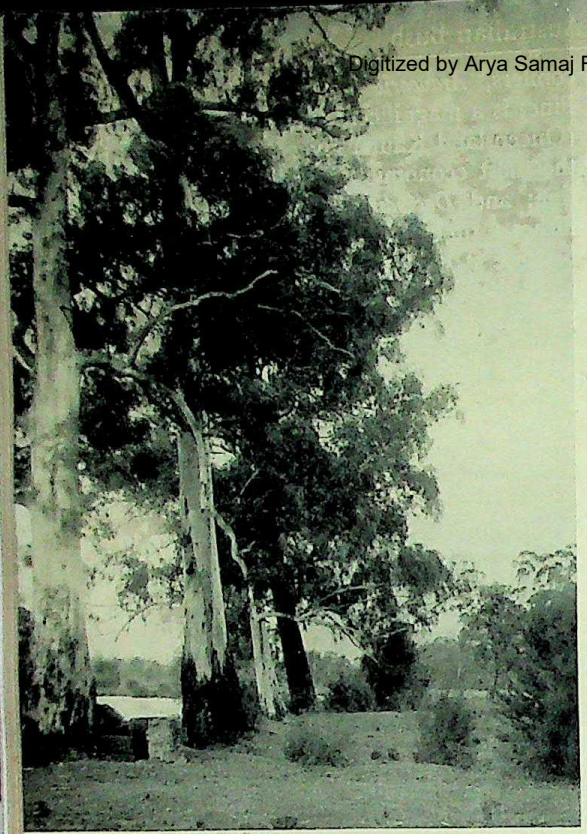

URE 5 – Eucalyptus rostrata (*Murray Red Gum*). *Near burton, Victoria. This is the most widely distributed of all* alyptus *species, as it grows on the banks of nearly every river e interior of Australia.*

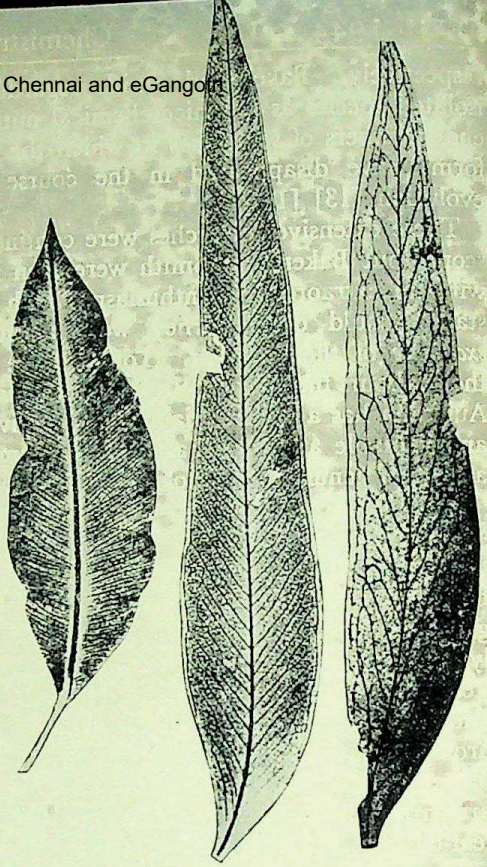

FIGURE 6 – *Types of* Eucalyptus *leaf-venation:* E corymbosa (*Group* 1), E. smithii (*Group* 2), E. radiat (*Group* 3). *Since the leaves are used as negatives, the oil glands appear as black dots. (Natural size.)*

FIGURE 8 – dl-*Menthol from piperitone. This specim contains the finest crystals of the* dl-*form of natural menth on record, measuring up to about* 8 *cm. long.*
(From a photograph by J. Gerrard, St Andrew

FIGURE 7 – Darwinia fascicularis. *The leaf-oil of this Australian shrub is a rich source of geranyl acetate.*
(From a photograph by H. G. Smith.)

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respectively. Baker and Smith regarded such conifers and *Araucaria cunninghamii* (Moreton Bay Pine) is a magnificent timber tree; *Agathis robusta* (Queensland Kauri) gives an oleo-resin which is the most economic Australian source of a turpentine; and *Dacrydium franklini* (Huon Pine) furnishes a timber very resistant to insects, possibly because it contains methyl-eugenol. Unfortunately, before the advent of scientific forestry in Australia, there was a reckless 'cutting out' by skilled axe-men of these unique and magnificent species, without replanting.

isolated species as botanico-chemical outliers, or end members of sequences in which the passage forms have disappeared in the course of the evolution [13] [14].

These extensive researches were continental in scope, but Baker and Smith were men imbued with an extraordinary enthusiasm which no obstacles could daunt. They were apostles *par excellence* of the eucalypt. Towards the end of their labours they wrote: 'In the genus *Eucalyptus*, Australia has a commercial asset of so diversified and valuable a nature that it has no compeer in any other genus in the whole botanical world.'

MORE ABOUT AUSTRALIAN PLANT CHEMISTRY

Although the genus *Eucalyptus* overshadows the bush, there are many other Australian plants of great chemical interest [13]. Thus, besides eucalypts, myrtaceous plants include the so-called 'tea-trees,' belonging to *Melaleuca*, *Leptospermum*, and other genera, the popular name for which arose from Captain Cook's reputed use of the leaves of *L. scoparium* as a substitute for tea. These are shrubs or trees with sweet-scented leaves: the leaf-oil of *L. liversidgei*, for example, contains 60 per cent. of citral; *L. citratum* secretes citronellal as well as citral. An even richer citral oil, consisting of the almost pure substance, is found in *Backhousia citriodora*. *Darwinia fascicularis*, a low shrub growing on waste sandy land, yields a valuable leaf-oil which vies with that of *E. macarthuri* as a source of geranyl acetate.

Many of the handsome Australian acacias, or wattles—of which more than four hundred species exist—exude gums. Certain species growing in the arid western areas yield a good gum arabic, but this cannot be collected economically. *A. pycnantha*, *A. mollissima*, *A. decurrens*, and other species give excellent tanning extracts; these tanbarks, however, can be grown and gathered more economically in South African plantations.

Many Australian conifers belong to *Callitris*, the genus *Pinus* being unknown in the indigenous flora. According to Baker and Smith [3] [13], the genus *Callitris* also underwent evolutionary changes in traversing the continent from west to east. *C. glauca*, a typical 'western' species, affords the best source of an Australian 'pine-needle' oil, containing pinene and bornyl acetate; but *C. tasmanica*, an 'eastern' species, yields an oil containing 60 per cent. of geranyl acetate, being, surprisingly, a conifer which might be worked economically for geraniol. Of other Australian

To sum up: the myrtaceous plants—*Eucalyptus* and its congeners—are remarkable for their wealth of essential oils; the Australian wattles and 'pines' are predominantly sources of astringent material. It is impracticable here to enumerate alkaloids, dyes, glucosides, saponins, starches, fibrous celluloses, and other important organic products which various investigators have isolated from Australian plants. Finally, however, space must be found for a mention of the dainty pink-petalled *Boronias* (*Rutaceae*), with their intriguing scents and interesting oils; of the sassafras and sandalwood trees; and of the Grass Trees, or 'black boys' (*Xanthorrhoea* spp.), renowned for a yellowish resin from which picric acid may be made.

PHYTOCHEMICAL AND CHEMICAL PROBLEMS

A study of the Australian flora presents many attractive problems to the botanist and the organic chemist. The botanist, sometimes unable to go so far as the chemist in the differentiation of plant forms, will ask where a species ends and a variety begins. An interesting example is provided by *E. dives*, the type form of which shows a maximum proportion of more than 50 per cent. of piperitone in its oil. This is a species of high commercial value, and yet botanically the type form is inseparable from three varietal forms, in which the proportion of piperitone dwindles from about 20 per cent. to vanishing point, with an increase of phellandrene in one variety and the development of about 25 to 75 per cent. of cineole in the other two [6]. To what extent can chemistry serve in the classification of living forms?

The admirable name *Eucalyptus* was synthesized by L'Heritier in 1788 from the Greek *eu* (well) and *kalyptos* (covered), the allusion being to a protective lid or operculum which covers the inner part of the flower and falls off when the stamens reach maturity. For this and other

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reasons, Baker and Smith considered that cross-fertilization occurs very rarely in the genus under natural conditions. Botanist and chemist alike would be interested to learn the effect of carefully controlled hybridization upon the chemical composition of eucalyptus oils. How would the chemical factors be inherited? Would it be possible to breed forms producing essential oils of particular value?

Some problems of a more purely chemical nature may be illustrated by referring to the ketone piperitone, which Smith showed in 1900 to be the peppermint-smelling ingredient of John White's Sydney Peppermint. This substance occurs in more than twenty *Eucalyptus* species, invariably in a laevo-rotatory or 'left-handed' (*l*) form. In 1921, J. L. Simonsen [12], working independently at Dehra Dun, India, discovered dextro-rotatory or 'right-handed' (*d*) piperitone in the oil of an Indian grass, *Andropogon jwarancusa*. These two piperitones, of the southern and northern hemispheres, are identical, except that their molecules are related as object and distinct mirror-image. A systematic study of the two forms of piperitone, begun at Sydney and continued at St Andrews [5] [9], has thrown much light upon chemical and stereochemical problems in the terpene group, besides leading to ideas of biochemical significance.

Firstly, by means of a network of delicate reactions, piperitone has been used as a source of each of the four menthols. Theoretically, each kind should exist in a 'right-' and a 'left-handed' form, together with a so-called *dl*-form composed of equal amounts of the two. As an outcome of this work, all of them have now been brought within reach of the chemist. One of the twelve forms (*l*-menthol) is identical with natural menthol from oil of peppermint (*Mentha piperita*).

Secondly, it has been found possible to proceed, by laboratory processes, from the 'left-handed' Australian piperitone to the 'right-handed' Indian piperitone, a stereochemical achievement of great interest.

Lastly, these chemical and stereochemical researches offer a clue to the biochemical relationships of the constituents of the Australian and Indian oils concerned. Baker and Smith held that the open-chain compound geraniol passed into *Eucalyptus* from the older genus *Angophora*, and probably runs through the whole genus, although often present only in small amounts. This view being accepted, geraniol is now presumed to function in *Eucalyptus* as the precursor of piperitol, piperitone, and phellandrene. A detailed theoretical scheme has been advanced, according to which the reactions take a slightly different turn in the Indian grasses, leading thereby from geraniol to piperitol and piperitone, with carene in place of phellandrene. The possibility of the two series of chemical reactions is clear, and some of the steps have been realized in the laboratory since the theory was first put forward; but in what way the plants discriminate between the 'left-handed' and 'right-handed' molecules remains obscure.

'The excessively delicate control of the molecular mechanism which is here implied appears to be a prerogative of the living organism. The organic chemist is powerless to effect such subtle differentiations by the artificial methods of the laboratory. At the present stage of our knowledge, the finer manifestations of organic synthesis appear to be inseparably bound up with vital processes' [9].

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The British Association

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O. J. R. HOWARTH

The British Association for the Advancement of Science has acted as a model for many similar societies in different parts of the world. Dr Howarth, who has been Secretary of the Association for many years, and has an unrivalled knowledge of its history, here describes its origin, aims, development, and present-day activities. During the war, the Association has paid much attention to the coming problems of reconstruction and rehabilitation.

The objects of the British Association for the Advancement of Science, as set forth by its founders, are these:

> To give a stronger impulse and a more systematic direction to scientific inquiry; to promote the intercourse of those who cultivate science in different parts of the British Empire with one another and with foreign philosophers; to obtain more general attention for the objects of science, and the removal of any disadvantages of a public kind which impede its progress.

We are to glance now at the Association's history; and the form of these words has a historical interest in the use of the comparatives—a *stronger* impulse, a *more* systematic direction, *more* general attention. The year of the foundation was 1831. The period was one of adjustment in Europe—adjustment to peace after the Napoleonic wars, and to all the changes, for good or evil, connected with the industrial revolution. As for science, a century earlier there were a few intellectual people who were turning away from speculation in thought and toward the collection and interpretation of facts. As has been written elsewhere:

> these few started a mighty movement. And once the expanses of science began to be visualized, however dimly, science might appeal to any person with any capacity of thought at all: it dealt with things you could see or touch, from the stars in their courses to the wayside plant, from the expansion of steam in a kettle to the strange animal from a foreign land; and its applications were concerned with affairs of everyday life.

By the beginning of the nineteenth century the day of specialization was dawning: in the first half of that century twenty-four of the leading learned societies of London were established, about fifteen of them between 1830 and 1850. The founders of the British Association disclaimed any intention of trespassing upon the ground of such societies, and did not in fact do so, as will appear. But between them they provided the means to stronger impulse and more systematic inquiry.

In regard to relations with the State and the people, however, science felt itself neglected, and through the lips of some of its chief exponents said so in no uncertain terms. There were, and always have been, some, and some of the greatest, seekers after knowledge who were (and are) content with seeking for its own sake, not parsimonious of imparting their results to others, but at the same time little, if at all, concerned with the bearing of those results upon any wider interests. The position about 1830, however, was that a powerful element in the scientific community recognized the existence of other communities, whether willing to learn something of the meaning of science, or indifferent, or antipathetic to it, and conceived it to be the duty of science to foster the first of these and to join battle with the others. They were right: the British Association in its early years gained plenty of support, but also encountered both indifference and antipathy.

Scientists who at that period were dismayed at the state of science in Britain looked elsewhere for an example of better conditions and found it in Germany, a land then at a stage of enlightened progress in more than one direction. Here had been founded, in 1822, a society taking all science and the arts for its field, and designed to hold annual meetings in successive cities throughout the country. Its name was the Deutscher Naturforscher Versammlung. British scientists attended its early meetings and found in it a model. In Britain, scientific societies outside London were much less numerous than they afterwards became, but some already flourished locally. To one of them, the Yorkshire Philosophical Society, Sir David Brewster—editor, encyclopaedist, teacher, and physicist—addressed himself. Would the

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society collaborate in organizing a meeting of friends of science in the city of York—centrally situated and easy of access from all parts of the country—with a view to the establishment of a permanent association? The society would, and did. And thus was brought to birth, on 26th September, 1831, the British Association for the Advancement of Science, with aims and practices so wisely defined by the group of leaders in science who attended the occasion that they survive in all essentials today, and have served as a model, even to the title, for similar bodies since established in other countries. Charles Dickens might pillory the professors of the 'Mudfog Association for the Advancement of Everything'; an astonishing dean of the Church of England might compose diatribes on 'The Dangers of Peripatetic Philosophy' and 'The Bible defended against the British Association'; but the movement prospered.

Brewster, as president of the Association in 1850, reviewed the preceding years, and mentioned many who had been or still were its active supporters: all were eminent in the science of their day, and the names of some will remain so always—Murchison, Dalton, Buckland, Whewell, Sedgwick, Airey, Herschel, Babbage, Lubbock, Lyell, Faraday, and the like. The Association was discharging its function of promoting contact with 'foreign philosphers,' and such names as Arago, Bessel, Struve, Liebig, and Agassiz appear among those of guests at its meetings. Pursuant to its undertaking not to trench upon the ground of other great societies, the Association never met in London until, by common consent, it did so for its centenary meeting in 1931. But in successive annual meetings it has visited all the biggest cities and towns in England, Wales, Scotland, and Ireland; it does so by invitation from the places themselves, and invitations have never been lacking. Only in years of war—1917 and 1918, and since 1939—have the annual meetings been intermitted. The founders had foreseen the possibility of movement beyond the confines of the home islands; but it was not until 1884 that the Association first held a meeting overseas—at Montreal. Since then Canada has been visited three times (1897, 1909, 1924), South Africa twice (1905, 1929), and Australia once (1914). 'Those who cultivate science in different parts of the British Empire' have thus been given the opportunities for contact promised by the Association. Moreover, a new precedent was established in 1937–38, when the Indian Science Congress Association invited to its jubilee meeting a representative scientific delegation organized by the British Association; and many of us hope that that precedent may be followed more generally in the future. The Association, under its charter, is free to wander where it is bidden; and delegations to kindred bodies, both within the Empire and elsewhere, should be within the bounds of possibility in years to come.

From almost its first years, the Association devoted to the promotion of scientific research and inquiry any funds which remained in hand after meeting working expenses. These funds have never been large, even in recent years when generous gifts were made to the Association by Sir James Caird of Dundee (1912), specifically for research, and by Sir Charles Parsons (1921) and Sir Alfred Yarrow (1926) for the general purposes of the Association. The inquiries thus modestly assisted have been supplemented by an immense amount of voluntary labour, and have covered a very wide range. Two features call for remark: one, the frequency of inquiries initiated by the Association and subsequently carried on by Government or other agencies more appropriate and better able to finance them; the other the method of calling for reports 'on the state of science' in any given department, according with the 'more systematic direction' of inquiry aimed at by the founders.

The compilation of the British Association Catalogue of Stars, seismological and tidal investigations, terrestrial magnetism, the computation of mathematical tables, British rainfall, marine biology, are all among subjects on which the Association focused inquiries during the first ten years of its existence. With some of them (notably seismology and mathematical tables) the Association has continued to concern itself to this day. The Association's work on electrical standards, initiated in 1861, resulted in the formulation of the system adopted internationally in 1908. Among other inquiries there may be mentioned anthropometric investigations in the British Isles (from 1875), which provided the basis for other such studies of later date, and in particular proved their value when during the war of 1914–18 it became necessary to take stock of the country's man-power. Investigations connected with early man have always been prominent. The engineering section has set on foot many practical inquiries; the education section has issued many factual reports on the position of science as an educational subject. In the realm of economics, it has been authoritatively

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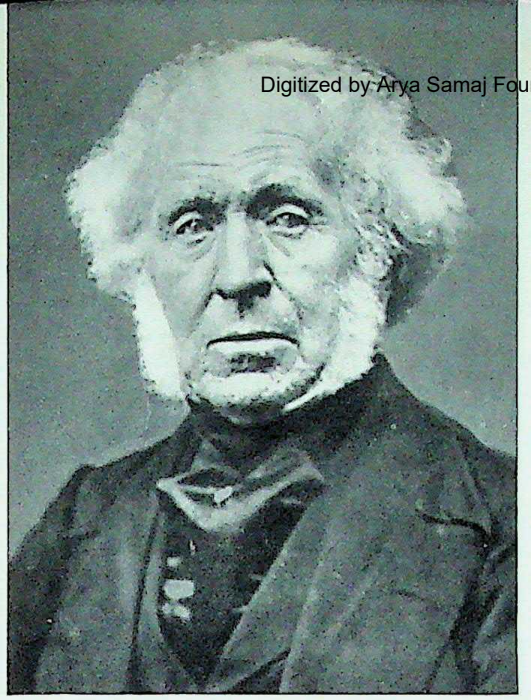

FIGURE 1 – *Sir David Brewster* (1781-1868). *Physicist, editor, encyclopaedist, and Vice-chancellor of Edinburgh University. A founder of the British Association.*

FIGURE 2 – *Sir Richard Gregory, Bt., F.R.S. The present President of the Association.*

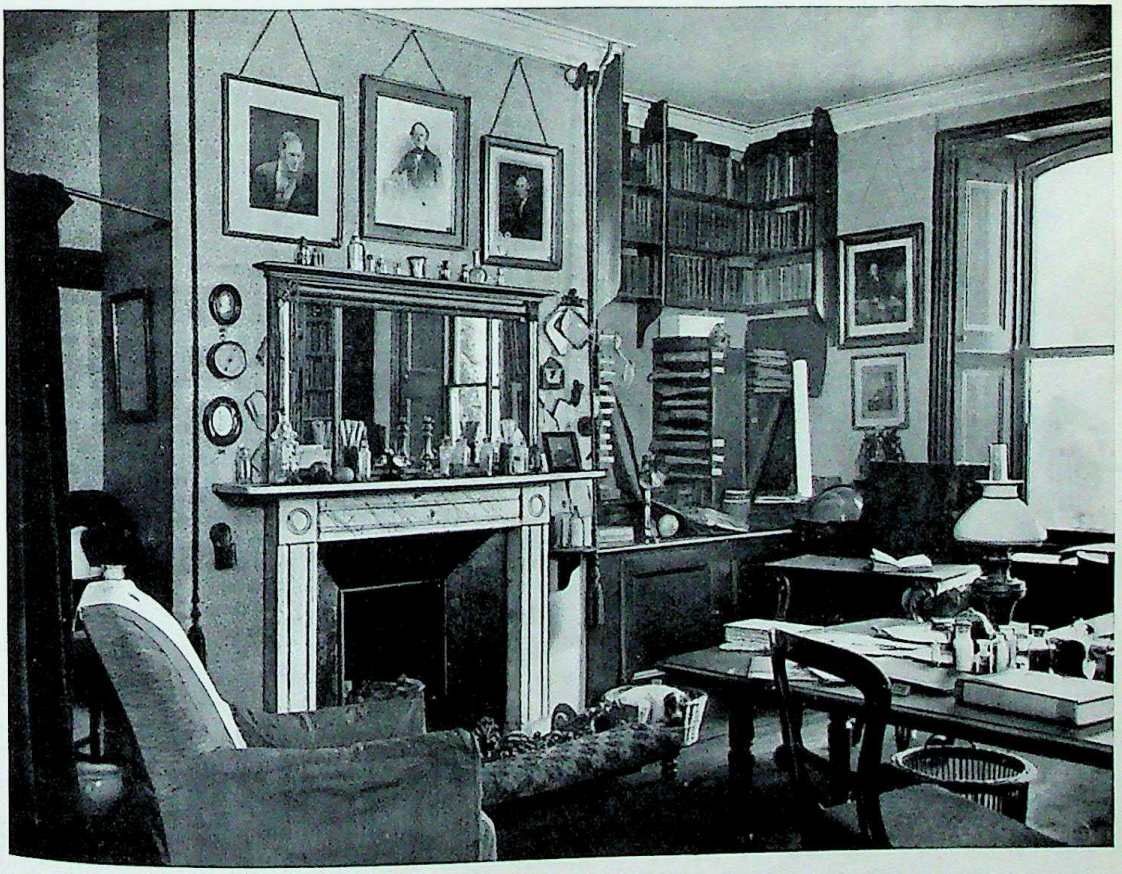

FIGURE 3 – *Charles Darwin's study at Down House, Downe, Kent. In this room* The Origin of Species *and many other books were written.*

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stated that the Association's work in connection with the patent laws of 1883 and 1885 'represents one of the most powerful public acts in its history.' One other incident connected with the Section of Economics should find place here because it must have few if any parallels in the history of scientific societies. The Association met in Belfast in 1874 at the time of a protracted strike in the linen industry. The Section of Economics was to receive a report and papers in which the subject of strikes was included incidentally. Representatives of masters and men in the industry were invited to attend, and discussion naturally centred on their own particular dispute. Economists present were able to apply such healing balm that it was possible for Tyndall, president of the Association, to announce next day that the dispute had been settled then and there.

Consideration of space denies the extension of this list, jejune as it may appear when joined with the remembrance that inquiries carried on under the auspices of the Association during the past century run to many hundreds in number. But before leaving this side of the Association's activities we must recall the episode of Kew Observatory. This institution existed a century before the Association was founded, and for a period it belonged to the Crown; but in 1841 it was on the point of being abandoned when the Association took it over and maintained it from 1843 to 1872. During this time it fulfilled many important functions, the chief of which was perhaps that of a testing-house for magnetic and meteorological instruments, watches, and various other appliances which needed the control of standards. The Observatory passed into the hands of the Royal Society in 1872, and so continued until early in the present century; and through the action, first of the Association and then of the Society, there may be traced in succession the origins of the great National Physical Laboratory of the present day.

The presidency of the Association, accounted one of the highest of scientific honours, is an annual office. Only in war-time has this rule been suspended: thus the late Sir Arthur Evans held office in 1917–18, and the present president, Sir Richard Gregory, was appointed in 1940. In the early years of the Association a layman of noble rank and high standing in the locality of the meeting was sometimes inducted into the chair—that practice accorded with (what is called) the spirit of the time. Moreover, the active interest of the Royal Family was shown by the acceptance of the presidency by the Prince

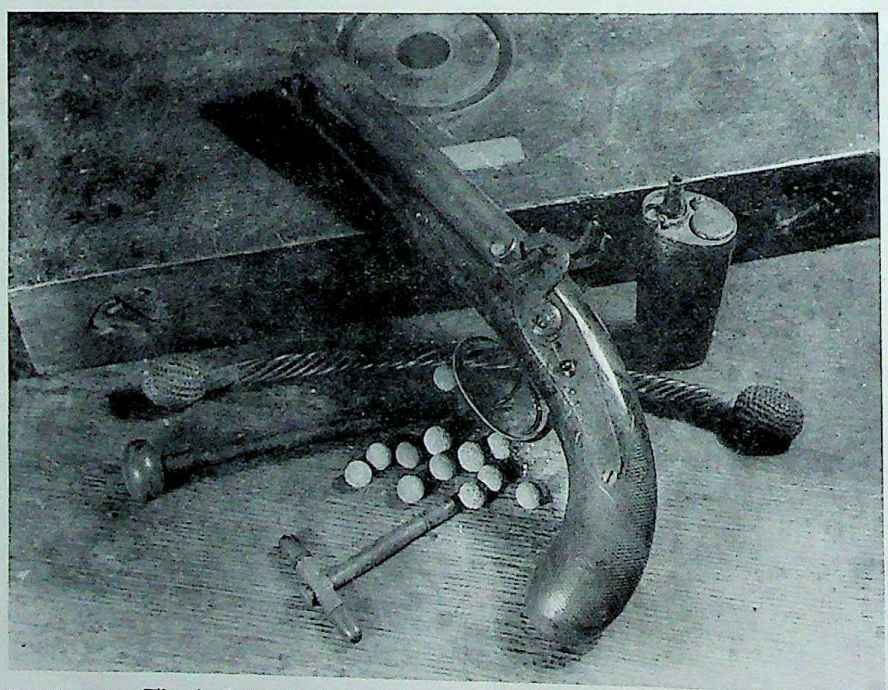

FIGURE 4 – *The pistol, powder-flask, bullets, ramrod and key, and a "blackjack," carried by Darwin on the voyage of* The Beagle, *and now in the custody of the British Association.*

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Consort in 1859 and by the Duke of Windsor (as Prince of Wales) in 1926; and it may be added here that King Edward VII in 1904 conferred upon the Association the royal patronage which has been continued by his successors, and that the Royal Charter of incorporation was granted in 1928.

Apart from these occupants of the chair, the list of presidents includes, it may be said, every most eminent name in British science during the lifetime of the Association—save one, and that among the most eminent of all: Charles Darwin. It was his poor health alone that forbade his acceptance of the office. It is the more fortunate that his name has been brought into peculiarly intimate relationship with the Association. The British Association provided one of the principal platforms for the discussion of his views as set forth in *The Origin of Species*. He himself could take no part in this: but his champions, such as Hooker and Huxley, did so powerfully, and so did his opponents, such as Owen and Bishop Wilberforce. Notably, the meeting of 1860 brought the protagonists together on the platform: of their performances thereon it need only be said that the scientific representatives presented their case with knowledge and dignity; their opponents with neither. Long afterwards, in 1927, Sir Arthur Keith, as president of the Association, reviewed in his address the position of 'Darwinism,' and pleaded for the preservation of Darwin's home at the quiet village of Downe, in Kent, as a national memorial, knowing that, given the necessary funds, the place could be acquired for that purpose. Next day it fell to the writer of this notice—and it was an unforgettable moment—to open a telegram from Mr (now Sir) Buckston Browne, F.R.C.S., a fervent admirer of Darwin, offering to acquire the property for the purpose which the president had in mind. The thing was done: the donor acquired Down House forthwith, restored it, and gave it in trust to the Association, with an endowment towards its upkeep, in 1929. Many relics of Darwin's own were forthcoming from many generous sources and are preserved in some of the rooms. In particular, the study in which he wrote all his most famous works was furnished almost exactly as he had it. These rooms and the pleasant grounds of the house were open to the public until war broke out in 1939; they had been viewed by thousands during the preceding ten years, and will be so again when peace returns. This is the inscription which guides visitors to the gates: 'Here Darwin thought and worked for forty years, and died, 1882.'

During the war of 1914–18 and for a little while afterwards there was some tendency on the part of the public towards dismay at the powers of science when put to evil uses. In the ensuing period the powers of science for good became increasingly manifest; but they were not, and still are not, sufficiently widely understood. The British Association must needs still strive for 'more general attention for the objects of science.' Important measures to this end were undertaken shortly before the present war. In 1936 the British Science Guild was incorporated into the Association. The object of the Guild (at that time under the presidency of the present Lord Melchett) was 'to promote the application of scientific method and results to social problems and public affairs.' The same object is implicit in those of the Association, and the union of the two bodies strengthened the Association in the discharge of its public functions.

Already in previous years those responsible for framing the Association's programmes had been increasingly insistent upon the inclusion of subjects of broad general interest at the annual meetings, but 'a more systematic direction' was needed for these. No one of the sections among which the work of the Association is distributed bore this specific charge upon it. A Division for the Social and International Relations of Science was therefore established in 1938, with the object of focusing attention on applications of science to the public benefit and of stressing the international character of science; for among all human activities science has approached most nearly to the ideals of international collaboration. The new Division differed administratively in some respects from the Sections, notably in being empowered to hold meetings independently of the general annual meetings.

This power has been used during the present war. It was clearly impossible under war conditions to hold the great annual meetings of peace-time. But the Division has been able to arrange conferences, simple in organization but effective in result, taking for their field problems of post-war rehabilitation and settlement, towards which science has essential contributions to make. The first of these conferences was held under the title of 'Science and World Order,' and reviewed a whole series of such problems. It attracted wide public attention and disclosed a number of subjects which demand further treatment.

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The evolution of British cartography

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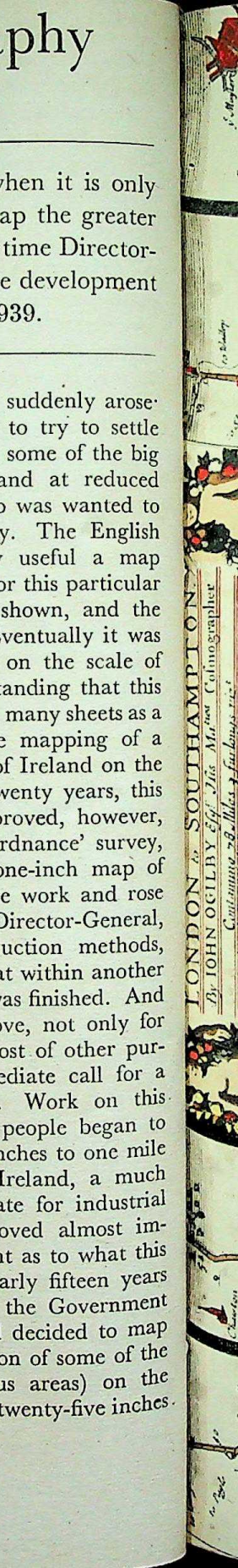
M. N. MacLEOD

There are few who do not respond to the mute appeal of a map—even when it is only penny plain and not twopence coloured—and the larger the scale of the map the greater its power of attraction becomes. Major-General MacLeod, who was for some time Director-General of the Ordnance Survey of Great Britain, here relates the story of the development of British cartography from the beginning of the nineteenth century up to 1939.

A map is a conventional picture of a part of the earth's surface on a sheet of paper or the like. Maps which show large areas, such as whole countries, whole continents, or even the whole world on a single sheet, are called 'atlas' maps. Those which portray a country on several sheets fitting together to form a 'series' are generally known as 'topographical' maps, though there is no hard-and-fast dividing line between the two.

The earliest known maps are all of the first type. The now familiar maps used by walkers, motorists, engineers, estate agents, etc., are comparatively new things in the world's history, dating only from about the end of the eighteenth century. The ancients do not seem to have had anything at all similar, though they may have had route maps, and 'cadastral' maps showing only property and field boundaries. The first nation to publish a topographical map of its country in the modern style was the French. The surveys for this map were started in 1745. The British followed towards the end of the century with a map on the scale of one inch to one mile, the first sheet of which was published in 1801. This map was produced in order to assist the Army in the defence of the country—the need for such assistance having been much felt in Scotland during the suppression of the '45 rebellion—and its production was placed under the direction of the Master-General of the Ordnance, who at that time performed most of the functions of the present Minister of Supply.

Progress on the map was slow at first. There was no recognized technique for surveying on such a scale; and the soldiers who were charged with the work had virtually to invent their technique as they went along. By the time that Napoleon had been finally liquidated at Waterloo, and defence had ceased to be a matter of pressing concern, only about half of England had been done. A few years later, however, another urgent need, of a different kind, suddenly arose. The British Parliament decided to try to settle the Irish question by buying out some of the big landlords and reselling their land at reduced rates to smallholders, and a map was wanted to help in carrying out this policy. The English one-inch map had shown how useful a map could be for such purposes, but for this particular purpose every field had to be shown, and the one-inch scale was too small. Eventually it was decided to try to map Ireland on the scale of six inches to one mile, notwithstanding that this would require thirty-six times as many sheets as a one-inch map. Seeing that the mapping of a part of England about the size of Ireland on the one-inch scale had just taken twenty years, this was a very bold decision. It proved, however, to be a very wise one. The 'Ordnance' survey, still plodding along with the one-inch map of England, was entrusted with the work and rose nobly to the occasion. Its Director-General, Colby, by applying mass-production methods, accelerated progress so much that within another twenty years the great new task was finished. And so useful did the new map prove, not only for land purchase, but also for a host of other purposes, that there was an immediate call for a similar map of Great Britain. Work on this was started at once, but soon people began to point out that if a scale of six inches to one mile was so useful in agricultural Ireland, a much larger one would be appropriate for industrial England. Unfortunately it proved almost impossible to secure any agreement as to what this larger scale should be, and nearly fifteen years of controversy followed before the Government took another bold decision and decided to map Great Britain (with the exception of some of the sparsely populated mountainous areas) on the scale of 1/2,500, or a little over twenty-five inches to one mile.



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LONDON to SOUTHAMPTON

By JOHN OGILBY Esqr. His Majesties Cosmographer

Containing 78 Miles of Curious Road

From the Standard in Cornhill LONDON to Bagshot in the Lands end Road
78 miles 6 furlongs there to Farnham 4 to Alton 9 1/2 to Alresford 9 1/2
to SOUTHAMPTON 15 Come to Salisbury Cont this 45 m 5 furlongs viz.
From SOUTHAMPTON 15 Come to Salisbury Cont this 45 m 5 furlongs viz.
to Stockbridge 8 to Andover 8 to Hatherden 8 to Ludgarshall 8 to Pewsey 8 to Salisbury
And to the City of Exeter 82 miles 5 furlongs viz. From SALISBURY 8 miles 2 furlongs
to Amesbury 8 to Shrewton 8 to Winterbourn Stoke 8 to Stapleford 8 to Wilsford 8 to
Lavington 8 to Devizes 8 to Rowde 8 to Bromham 8 to Chippenham 8 to Kingsweston 8
to Bristol 8 to Keynsham 8 to Bath 8 to Batheaston 8 to Claverton 8 to Bradford 8 to
Trowbridge 8 to Steeple Ashton 8 to Melksham 8 to Beckington 8 to Frome 8 to Mells 8
to Whatley 8 to Hilcot 8 to Shepton Mallet 8 to Pilton 8 to Glastonbury 8 to Meare 8
to Ashcot 8 to Bridgwater 8 to Enmore 8 to Taunton 8 to Wellington 8 to Collumpton 8
to Cullumpton 8 to Hele 8 to Exeter

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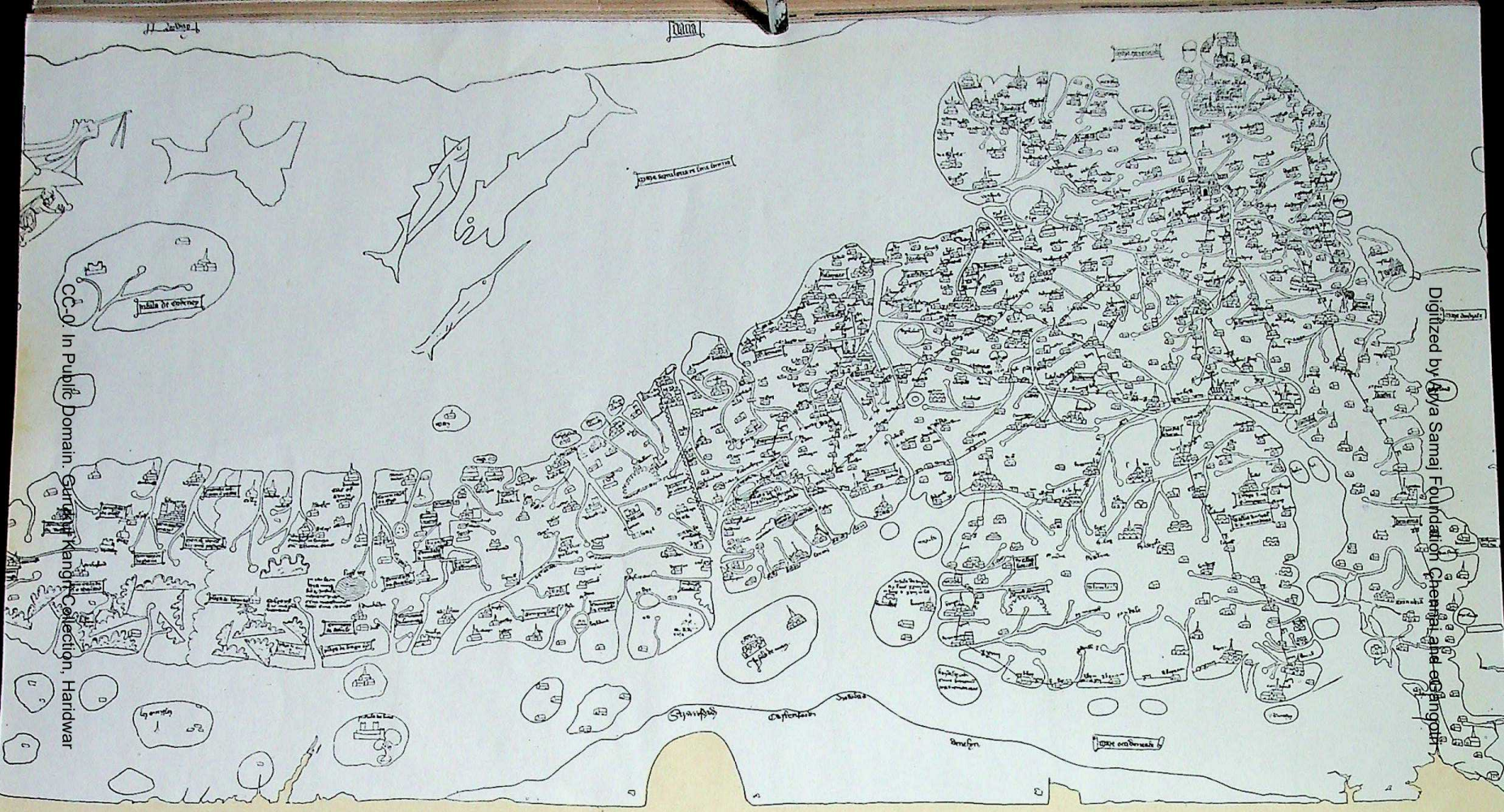

FIGURE 2 – *A portion of a fourteenth century map of England. The original is in the Bodleian Library.*

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FIGURE 3 – *An extract from the latest gridded edition of the Ordnance Survey one-inch map.*

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1 – *Part of the same area as that shown in figure 3 as it appears on the first (engraved) edition of the Survey one-inch map of Great Britain.*

5 – *A smaller part of the same area shown on a modern gridded 1/2,500 scale plan.*

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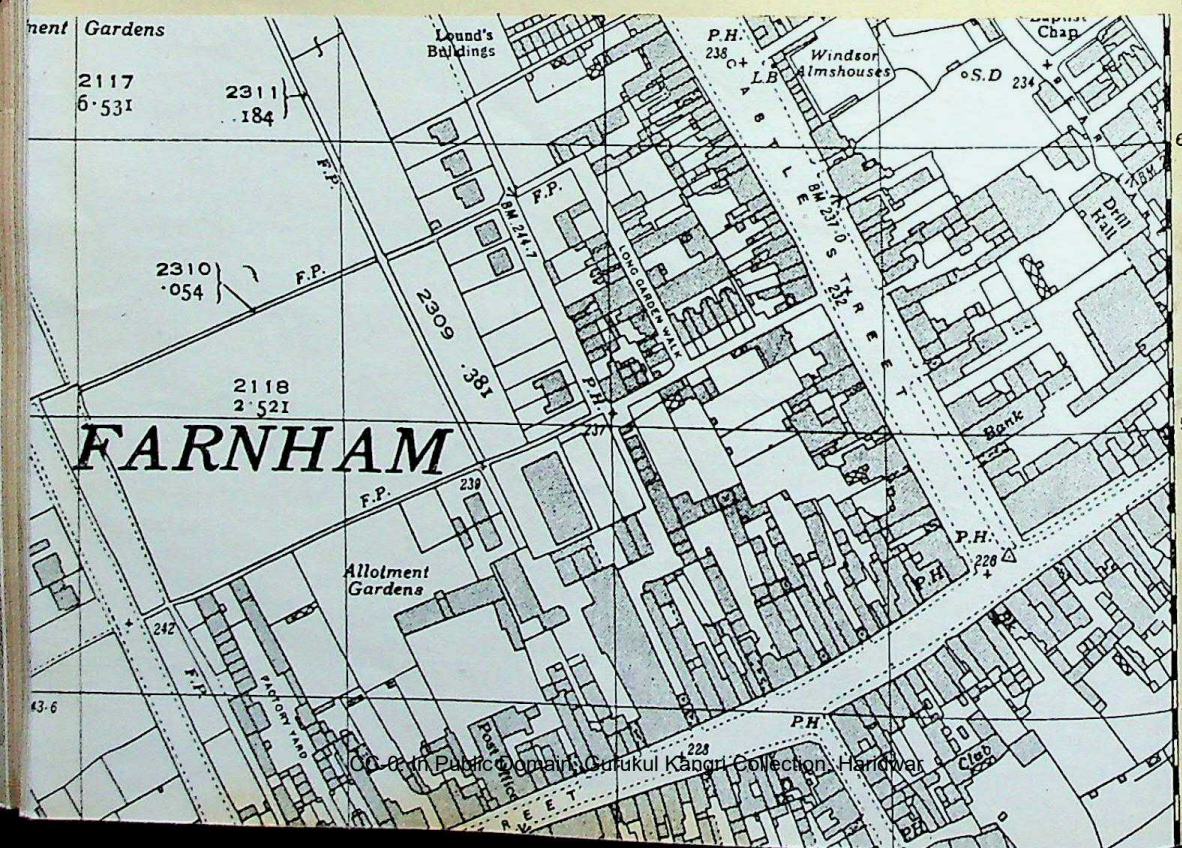

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This was a prodigious task, involving a thorough overhaul. The reasons for embarking upon this formidable task are rather too technical to be given here, but the fact that such admirable maps should need overhauling only fifty years after their completion is a useful reminder that there is no finality in cartography. Man and nature are continually changing the face of the country, and a first-class map must record these changes without undue delay. In Great Britain the need for periodical revision was apparent long before the original survey was finished, and authority was given in 1882 for the publication of revised plans at intervals of twenty years. Revision did not actually start until 1896, and was then done county by county in rotation. The 20-year period was maintained, and sufficed reasonably well, until the outbreak of war in 1914, when the work of revision had inevitably to be greatly restricted. When peace was restored, the development of the motor-car led to a campaign of road and house construction which caused such rapid and extensive changes in the countryside that revision of the maps lagged sadly behind. Before long, the obsolescence of British maps, upon which many people had come to depend, began to cause the greatest inconvenience, and when Parliament passed such Acts as the Housing and Slum Clearance Act of 1930, and the Finance Act of 1931 which taxed land values, matters reached something like a crisis, since Acts of this kind cannot easily be administered without good and up-to-date maps. After the Town and Country Planning Act of 1933, the Government decided to take action, and, on the advice of a Committee presided over by Viscount Davidson, provisionally approved a number of measures which would, in due time, have restored British maps to something more than their old level of excellence. The outbreak of war in 1939 again interfered with the execution of these plans, but the episode has been useful in showing, on the one hand, that well-executed and reliable maps are now much more than a mere convenience, and are in fact almost indispensable tools—in peace no less than in war—for the orderly and efficient conduct of affairs; and, on the other, that mapping, even with the aid of the most recent technical devices such as air photography, is a slow process which cannot be suddenly and indefinitely accelerated by Acts of Parliament or grants of money, however liberal. It is to be hoped that the stress of greater events will not cause the lesson to be overlooked or forgotten.

50,000 sheets, in addition to over 10,000 sheets of the six-inch map which was to be published as well. No other country has yet attempted anything like this. None has mapped all its territories even on the six-inch scale and not many have managed even half this size. The British 1/2,500 map was started in 1855 and took about forty years to complete. It now forms the basis of a whole range of maps on scales down to 1/1,000,000—the scale of the *Carte Internationale du Monde*.

Only fifty years have elapsed since the great twenty-five-inch map of Great Britain was finished, and half a century is not a long time in the life of a nation. While there is no doubt that the country gets very good value from the map, it is probable that, as it continues to gain experience, it will be able to get still more. New uses for good and reliable maps are constantly being found; but it is becoming clear that the fullest value of any particular map can be secured only when it forms part of a well-arranged cartographic system, in which there are several types of map, on scales related to one another in convenient ratios; so that any project or operation can be studied as a whole on maps of small scale, and its subdivisions examined separately on maps of larger scale showing the ground in greater detail. British maps were not, of course, designed for use in this manner, but changes which were about to be made when this war broke out—and which will doubtless be made as soon as peace is restored—will improve them in this respect. Among these changes is the addition of a 'grid,' a cartographic device invented during the last war in order to provide a means of indicating the positions of points and places not named on the map. A map grid is, in effect, a graphic representation of the rectangular co-ordinates used by mathematicians for defining the positions of points on a plane surface, and appears on each map as a network of squares, any one of which can be indicated by a number, called a 'map reference.' In addition to other uses, a map grid greatly facilitates the comparison of one map with others of the same area on different scales.

The addition of a grid was not the only contemplated improvement in British maps, though it was perhaps the most interesting. There was also an intention to rearrange the sheets of the 1/2,500 and six-inch maps in a more convenient form, and to take the opportunity of giving them

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New precision in atomic constants

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H. R. ROBINSON

The absolute masses of individual atoms, and the magnitude in electrostatic units of the electronic charge, are now known with an accuracy of 1 part in 4,000 or 5,000. How this precision of measurement has been achieved is here explained by Professor Robinson, who sketches the successive stages of progress from the pioneer work of Sir J. J. Thomson to contemporary data provided by the latest types of mass spectrograph.

Here is an extract from an edition, published about 1850, of the Reverend Jeremiah Joyce's *Scientific Dialogues:*

Emma: I remember, papa, that you told us something strange about the divisibility of matter, which you said might be continued without end.

Father: I did, some time back, mention this curious and interesting subject, and this is a very fit time for me to explain it.

Charles: Can matter indeed be infinitely divided; for I suppose that this is what is meant by a division without end?

Father: Difficult as this may at first appear, yet I think it very capable of proof. Can you conceive of a particle of matter so small as not to have an upper and under surface?

Charles immediately sees the point of this leading question, and deduces, at some length, that matter *must* be infinitely divisible. Father approves: 'Your conclusion is just.'

In a later edition, of 1875, revised by 'men eminent in science' and 'completed to the present state of knowledge,' all the above, including Papa's approval of Charles' conclusion, is reprinted without change, but with the addition of a very cautious rider, saying that most philosophers now adopt the atomic view of matter, 'although it is perhaps a question which is incapable of satisfactory solution.'

This quotation has not been introduced with the unworthy object of poking easy fun at an outdated text-book of elementary science. Joyce's *Dialogues* were, in and for their time, like the celebrated *Conversations* of Mrs. Marcet, an excellent introduction to popular science. The extract is intended simply to serve as a reminder of the great change that has occurred, in the last seventy years, in our attitude to atomic theory. In spite of the contributions made by Dalton, Gay-Lussac, and Avogadro in the first few years of the nineteenth century, it was not until nearly the end of that century that Dalton's atomic theory was fully recognized as anything more than a convenient and powerful working hypothesis. Today, in a hypothetical new edition of the *Dialogues*, Papa would certainly take the 'reality' of atoms and molecules as axiomatic, and (if he could keep them from prattling about Fermi-Dirac statistics) he would be likely to give the children at least a simplified account of Aston's work on isotopic masses.

Atomic theory owes much of its present authority to the detailed and accurate knowledge of the properties of individual atoms and molecules which has been accumulated during the last few decades, and more particularly since the development of electrical theories of matter. It is the purpose of this article to indicate some of the ways in which this knowledge has been acquired.

Oddly enough at first sight, the first molecular magnitude to be accurately known was the average value of the molecular speed in a gas; it is over ninety years since that extraordinary genius, J. P. Joule, deduced an approximate expression for the pressure of a gas in terms of the gas density and the square of the mean molecular velocity. Soon afterwards Clausius derived the more exact expression in which the mean square velocity replaces the square of the mean velocity, and since 1859, when Clerk Maxwell obtained the law of distribution of molecular speeds, we have known the precise ratio between these two means, and even the fraction of the molecules of a given gas whose speeds lie, at a given temperature, between any two assigned limits.

I have no knowledge of any experimental work on molecular speeds earlier than that of Cantor, carried out in Strasbourg in 1897. What Cantor did in effect was to measure the difference between the thrusts on two equal surfaces, one of glass and the other of copper, suspended in an atmosphere of chlorine. As the copper surface captures some of the chlorine to form a chloride,

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the number of molecules rebounding from it is less than from the glass surface, and the pressure is correspondingly lower. The measured difference, together with a knowledge of the mass of chlorine collected per second by the copper surface (obtained by weighing the plate at intervals of a few minutes), leads quite simply to a deduction of the mean square molecular velocity. All that can be said of Cantor's results is that they are of the order of magnitude predicted by the kinetic theory. The method is obviously not precise, and the experiment is unsatisfactory in a not uncommon way, viz. there are so many palpable sources of error that it would be almost as easy to dismiss the result if it did not agree with theory as it is to accept it when it does. The work deserves mention, however, as an ingenious early attempt to confirm the predictions of the kinetic theory of gases. It appears to be very little known, for I have mentioned it to a number of well-read physicists without finding one who had heard of it before. Direct experiments on molecular speeds and their distribution came much later, with the application of Dunoyer's method of working with well-defined molecular beams.

Sir J. J. Thomson.

Kinetic theory, combined with data from other branches of physics, also gave us our earliest estimates of the mass and size of the individual molecule—though none but the most naïve of physicists could ever have thought that he had a very clear idea of the exact meaning of the 'size' of a molecule. On the whole, however, the late Victorian scientists had considerable reason to be satisfied with the state of this particular branch of knowledge. The original method of Loschmidt was known to give upper limits for the mass and size, and other methods based on simple theories of dielectric action were known to give lower limits. The ratio of the upper to the lower limit varied somewhat from gas to gas, but 80 is a fairly representative value; further, a slightly more recondite argument, making use of the constant b in van der Waals' equation, very neatly split the difference between the two extreme values, so that molecular masses might be said to be known certainly in order of magnitude, and possibly to within 50 or 100 per cent. There was, however, nothing to show whether the subject of the calculations was a definite molecular mass, or merely an average value, corresponding to a group of many particles whose individual masses might vary, continuously or discontinuously, over a fairly wide range. A wide spread of the individual masses would have been revealed by diffusion experiments, but in the last century there was no experimental technique capable of detecting a spread of a few per cent.

We now know the masses of individual atoms to a degree of accuracy that would have seemed totally unattainable fifty years ago, and we know the nature of the spread in the masses, which is in fact discontinuous. The first steps in this amazing advance were made in the Cavendish Laboratory, by J. J. Thomson and the remarkable group of physicists he attracted to Cambridge. In 1897 Thomson, independently of and almost simultaneously with Wiechert in Berlin and Kaufmann in Königsberg, measured the specific charge of the negative electrons in a discharge tube; he deduced correctly that the electrons were far less massive than even the lightest atoms, and showed that they were constituents of all ordinary matter. Soon afterwards J. S. Townsend, by a brilliantly conceived and executed series of experiments, proved that the electronic charge, e, was identical in magnitude with the charge carried by a univalent electrolytic ion. Next, Townsend, Thomson, and H. A. Wilson made independent determinations of the electronic

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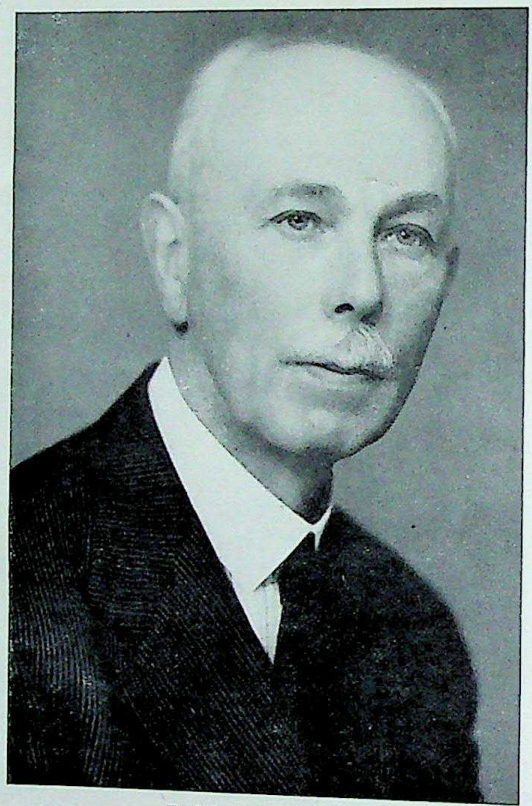
charge, using methods developed in the same laboratory by C. T. R. Wilson in his work on cloudy condensation.

From that time onwards—that is, from about the beginning of this century—there has been no room for reasonable doubt of the atomicity of electricity, and (if we ignore, for a moment, isotopy) the accuracy of our knowledge of individual atomic masses has been limited solely by uncertainty about the precise value of *e*. The derivation of the masses is very simple and straightforward, for since Faraday's pioneer work (1833) we have always had the means of knowing accurately the ratio of mass to charge of electrolytically transported atoms in bulk; it is simply given by the atomic weight, on the ordinary scale, of the elements concerned, divided by the valency and by Faraday's constant of electrolysis. According to Professor Raymond T. Birge, who knows more about these matters than almost everyone else combined, this bulk ratio of mass to charge is now known to within about 1 part in 10,000. We get the mass of a single atom by multiplying the bulk ratio by the charge carried by a single ion, which is $n \times e$ for n-valent elements.



F. W. Aston, F.R.S.

The Cambridge pioneer measurements of *e* were subject to relatively large errors, and it is to two United States physicists, R. A. Millikan and A. H. Compton, that we primarily owe our greatly improved knowledge of this important atomic constant. Millikan substituted fine oil-drops for the water-clouds used by Thomson and Wilson; thus, instead of being restricted to hasty observations upon the upper surface of a rapidly disappearing cloud, he was able to make prolonged measurements of the behaviour, under accurately controlled conditions, of an almost perfectly stable drop. He made a detailed study of the possible sources of error, and the result, which Millikan published in 1917, was generally supposed to be correct to within 1 part in 1,000. Later oil-drop experiments, notably the very recent ones made by Laby and Hopper in Melbourne (1941), have confirmed the remarkable accuracy of Millikan's work. It has, however, become clear that Millikan's final value for *e* was in error by about 7 parts in 1,000, this error being mainly due, not to inaccuracies in Millikan's own experiments, but to the adoption of an incorrect value of the viscosity of air in the calculation of the result.

Millikan's method was essentially an elaboration and improvement (the two terms are not necessarily synonymous in experimental science) of the older Cambridge experiments, whereas Compton's broke entirely new ground. Compton was the first to realize the possibility of using, under suitable conditions, an ordinary ruled diffraction grating for the spectroscopy of X-rays, and thus of measuring the wave-lengths absolutely. Such measurements, taken in conjunction with measurements of the angles of reflexion of the same X-rays from crystal faces, lead quite simply to an evaluation of *e*. Accurate crystal measurements were already available when Compton and Doan first succeeded, in 1925, in obtaining X-ray grating spectra. The first results, for which high accuracy was not claimed, were in approximate agreement with Millikan's *e*. Later work, in which the accuracy has been developed to a degree almost comparable with that achieved in crystal spectroscopy by Siegbahn and his schools in Lund and Uppsala, has led to a value of *e* which is generally accepted as correct to within 1 part in 4,000 or 5,000. It is $4{\cdot}802_5 \times 10^{-10}$ absolute electrostatic units; Millikan's value was $4{\cdot}770 \times 10^{-10}$, and recent work on the viscosity of air tends to show that the difference between the two may very largely be explained

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away. The theory of the X-ray method has been subjected to very careful and competent scrutiny, with satisfactory results, and the value of e has been confirmed, in an elegant but less direct manner, by the X-ray refraction experiments of J. A. Bearden. There are therefore exceptionally strong grounds for confidence in the precision of our knowledge of the electronic charge, and hence of atomic masses.

The story is, however, incomplete without a reference to another field of research which has been intensively cultivated in the Cavendish Laboratory. Early in this century J. J. Thomson developed his well-known 'parabola' method of investigating the positive rays discovered in 1886 by Goldstein. In this method, charged atoms are deflected by parallel electric and magnetic fields, and fall ultimately upon a photographic plate. For a given charge, atoms of a given mass produce a parabolic trace upon the plate; if the mass of the atoms varied continuously over a certain range, the trace would be correspondingly broadened. In fact, allowing for inevitable broadening attributable to the geometry of the apparatus, there is no evidence of any such variation. In 1912, however, Thomson made the remarkable discovery that neon gave two distinct parabolas, lying closely side by side—showing, as one possibility, that neon atoms could be divided into two groups, both indubitably neon, corresponding to two definite and distinctive masses. This view was eventually substantiated, and some years later a third group was found, showing that there are three kinds of neon atoms.

Thomson's photograph of the parabolas of neon was the first clear indication of the existence of non-radioactive isotopes. It was the starting-point of a long chain of investigations which has shown that in most elements the atoms are not all identical in mass; they can, however, be resolved into definite groups—generally not very many groups[1]—of identical particles. It is in this sense that chemical atomic weights, and the early estimates of the masses of individual molecules, relate only to average values, viz. the means of the various isotopic masses, weighted according to their relative abundance.

Our knowledge of these matters is derived mainly from the work of F. W. Aston in Cambridge. Following a trail indicated by Thomson's parabolas, Aston began at once to try to separate a sample of pure neon gas into identifiably different components by diffusion. Later he turned to the more powerful method of separation of positive rays by electric and magnetic fields. In his first mass spectrograph (a celebrated instrument, now in the Science Museum at South Kensington) he created a research tool of vastly greater power than the parabola apparatus. It was ready for use in 1919, and with it Aston at once confirmed Thomson's result with neon, and showed that many other elements were mixtures of isotopes.

Since 1919 the isotopes of the chemical elements have been very thoroughly investigated; initially the bulk of the work was shouldered by Aston himself, with the original mass spectrograph and later with more refined models using the same principle. More recently other types, with very high performance, have been built and used by other workers—notably by Dempster (an early pioneer of positive ray analysis), Bainbridge, Jordan, and Nier in the United States and Mattauch in Vienna. In the two or three years preceding the present war, numerous other workers appeared in the field, and we now have an immense body of detailed and accurate knowledge of the relative masses and abundance of isotopes. In the measurement of relative masses an accuracy of 1 part in 100,000 is commonplace, and one part in a million is claimed for Jordan's latest instrument, announced in 1940. The knowledge so acquired has been of great value in very varied fields. It is as a mere by-product of it, and of the precision with which e has been measured, that we now know the absolute masses of individual atoms with an accuracy of about 1 part in 4,000 or 5,000, i.e. not much less accurately than we know so old-established a constant as the mechanical equivalent of heat. The mass of the lightest atom known is $1{\cdot}6734 \times 10^{-24}$ gram.

This sketch has dealt in the main with one aspect only of the properties of individual atoms and molecules—that is with no more than a very small fraction of the knowledge that has been acquired during the past forty-five years. I hope that it may be read in the light of a remark made by Kelvin in 1883: 'I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it.' If we accept this dictum (and it is a meiosis to say that there have been, and are, authorities whose dicta are in general less trustworthy than Kelvin's), enough has been said to show at least that we do now 'know something about' atoms.

[1] Tin, for instance, which is exceptionally complex, has ten isotopes, ranging from 112 to 124 atomic mass units, with a weighted mean of 118·70.

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Advances in the scientific knowledge of rubber

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E. H. FARMER

Rubber, with its enormous molecular weight (about 350,000), is a difficult substance to investigate chemically. The molecule is so long and twisted that only small, mobile, reagent molecules will act upon it quickly and completely. Recently, however, very much progress has been made in the chemistry of rubber, which Dr Farmer shows to possess a latent chemical versatility of great interest. This is likely to increase its utility to industry.

The rapid increase during recent years in the manufacture of synthetic materials, some of which possess a measure of rubber-like properties, has given an impetus to research into the fundamental characteristics and future economic possibilities of natural rubber. The discovery in 1839 that rubber can be vulcanized, by simply heating it with sulphur, and thereby transformed from a tacky, deformable, and somewhat elastic material into a non-tacky one having enormously improved elasticity, tensile strength, and stability in air, proved to be the foundation of the modern rubber industry. Rubber, as most people know it today, is vulcanized rubber, which means that most of the rubber articles of everyday life are essentially composed not of the rubber hydrocarbon but of a chemical modification of it. Hence the question arises: Is vulcanization the only useful chemical transformation in the rubber repertory, or can other chemical processes convert it into a range of materials each of which excels sufficiently in some group of physical properties to render it the most suitable material for a particular industrial enterprise? Some progress towards answering this question has been made along empirical lines during the past fifteen or twenty years, but a complete answer can be obtained only when the fundamental properties of the rubber hydrocarbon have been systematically investigated. Some recent discoveries which reveal unexpected capacities and complexities in the properties and chemical behaviour of rubber are reviewed in the following account.

THE SIGNIFICANCE OF THE MOLECULAR FORM OF THE RUBBER MOLECULE

When rubber had been shown by Pickles to be built up of recurrent isoprene units, $—CH_2 \cdot C(CH_3) = CH \cdot CH_2—$, linked end to end, it remained for Staudinger to assess the number of such units in the average molecule of the hydrocarbon. Staudinger's estimate of *ca.* 2,200 has now been revised after careful study by Gee [13], and stands at the value of *ca.* 5,000 (molecular weight, 350,000). The immense length of the molecule which Gee's value discloses provides certain embarrassments for the chemist, who has to bring the molecules to reaction in bulk. Viewed from the standpoint of classical organic theory, each rubber molecule contains in its chain an average of 20,000 carbon atoms (apart from those in attached methyl groups); it has an innate capacity for free rotation of its parts to occur about each of its 15,000 C–C links; and it displays a fixed *cis* configuration about its 5,000 double bonds. Some idea of what this means in magnitude and molecular form may be gauged from figure 1 [18], which represents a saturated paraffin molecule having about one-twentieth the chain-length of the rubber molecule, and not complicated by configurational restrictions arising from the presence of recurrent *cis* linkings. Such sinuous and unwieldy molecules must inevitably become badly entangled with one another, so that they are no longer able to move freely as a whole. Consequently successful reaction between the thousands of potentially reactive units comprising each chain and any reagent molecules that are placed in juxtaposition will be greatly facilitated by small size and ready mobility in the latter, since this will enable them to pass between the chains and approach the nearly immobilized rubber units.

COMBINATION OF RUBBER WITH SMALL AND LARGE MOLECULES

No difficulty is experienced in practice in bringing about *complete* and rapid reaction between all the units of the rubber chains and small,

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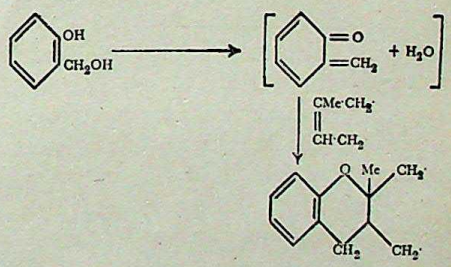
mobile, reagent molecules such as those of hydrogen chloride. On the other hand, where the reagent molecule is very large or is attached to a bulky catalyst surface, the problem of physical approach becomes acute. This is well seen both in the case of catalytic hydrogenation and in that of combination with phenol-formaldehyde resins. In these processes the practical difficulty of approach can be overcome in quite different ways.

The hydrogenation of rubber by treating it with hydrogen in the presence of a catalyst has engaged the attention of many chemists, because it has appeared reasonable to expect that if rubber were deprived of all, or nearly all, of its unsaturation it would then be resistant to atmospheric oxidation but would retain in large measure those properties dependent on its great molecular size. Hydrogenation proved in practice to be very difficult; and all the early workers believed that the difficulty in achieving substantial reaction was due to poisoning of the catalyst by impurities in the rubber, and hence was to be overcome by very drastic (and usually very deleterious) purification of the rubber. According to modern views, it is necessary for each of the ethylenic centres of the rubber to become adsorbed, at some point in the process, on the catalyst surface, in order to take therefrom the necessary pair of hydrogen atoms. Hence the physical problem is a little like that confronting an enormously long and three-dimensionally coiled worm, which, without straightening, must bring every segment of its body, one or more at a time, in contact with certain spots distributed over the ground. Only by prolonged and violent contortions may its object be achieved. Staudinger partly overcame the difficulty of hydrogenation by using a high temperature, a fairly high hydrogen pressure, enormous amounts of catalyst, and a very long reaction time. Hydrogenation does occur under these conditions, but serious cracking and cyclization changes readily occur too. It is now found possible, by adjusting the temperature of reaction within fairly narrow limits, and by using a supported nickel catalyst, to cut down to moderate values the amount of catalyst and the time of reaction required for complete hydrogenation; and also to reduce the working pressure to about 15–20 atms. [11]. The most critical feature is the temperature, for although a fairly high temperature (170–195° C) is necessary to promote the rather violent thermal agitation of the rubber chains requisite to secure effective contact of all the ethylenic units with the catalyst at a reasonable time, yet too high a temperature causes not merely the severe cracking and cyclization referred to above, but probably also the recombination of the thermal degradation products. This last occurrence is almost certain to lead to branching in the reconstituted chains. In practice, the rubber can be hydrogenated (with or without a measure of cracking as desired) to any required point up to complete saturation. The uncracked hydrogenated products are rubber-like solids, resistant to oxidation, and showing elasticity over a rather lower temperature range than rubber. Severely cracked hydrogenation products, on the other hand, are semi-solids (*see* figure 2).

RUBBER IN RESINS

A hitherto undescribed way of bringing about chemical combination of rubber with large molecules is to build up the latter on the former. This has been accomplished in the case of phenol-formaldehyde resins by uniting very simple phenol-formaldehyde condensation products ('Novolaks') with some of the ethylenic units in rubber, and afterwards cross-linking the resinous parts of the product. For this purpose the 'Novolaks' can be formed in presence of rubber by the aid of an acid catalyst, but only those aromatic nuclei which contain a $\cdot CH_2OH$ group in the ortho-position to a phenolic $\cdot OH$ group can be directly joined to rubber [4]. The unions occur quite easily at moderate temperatures and entail the formation of a chromane ring at each junction, as is shown for saligenin and ortho-ortho-linked disaligenin in equations (*a*) and (*b*). Subsequently



the dried rubber-'Novolak' resin can be ground with hexamethylenetetramine and employed as the resinous component of moulding powders and

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for the impregnation of textiles and paper. Hardening occurs when the mixture is heated and subsequently cooled. In technological practice somewhat oxidized rubber (commercial 'Rubbone') is used in place of raw rubber in order to ensure the compatibility of all the resin-forming ingredients. In this material, points of junction with the 'Novolaks' are believed to occur with fair frequency along the lengths of the rubber chains. A conventional representation of the kind of complex formed is given in figure 3.

The resin has the unique property among the resins of 'Bakelite' type of possessing some residual thermoplasticity after normal thermosetting has occurred. This very useful property enables flat sheets of resin to be bent, or pressed into curved forms, after being warmed to 120–130° C (*see* figure 4). The basic addition-reaction occurring between saligenin, di-saligenin, etc., and rubber appears to be applicable to a wide variety of other olefinic substances, not merely to rubber.

THE IMPORTANCE OF RADICALS

Rubber is a polyolefinic substance and hence has the ability to add suitable reagents at the double bonds of its units. This is now known to be only one of the ways in which it can react. It will be borne in mind that owing to its hydrocarbon character and relatively low solubility, rubber is almost invariably brought to reaction either dissolved in hydrocarbon solvents or in the solid form. In both these conditions the almost non-polar ethylenic units are surrounded by a non-ionizing medium. In such circumstances ionic reactivity is not favoured, and in its place a strong tendency towards another type of reactivity, *radical* reactivity, makes itself apparent, in which the participants are not electrically charged ions but neutral radicals and molecules. The main basis of this behaviour is the capacity of the rubber molecule to permit certain of its hydrogen atoms to be displaced or detached by the reagents it meets. What happens afterwards depends on circumstances, but the net result is that rubber is highly reactive, although the mechanism of reaction is often intricate.

A good deal of information about the radical reactivity of rubber has been derived by experiments on oxidation [10], [12], a process which proceeds sufficiently readily to cause the gradual deterioration (perishing) of rubber when the latter is exposed to air in a bright light without chemical protection. Naturally, the way in which oxygen acts has been studied very carefully in order to allow the most effective steps to be taken to prevent this deterioration. There are far too many units in any rubber chain to allow the chemist to tell what happens to any representative one of them during reaction, and the task is not rendered easier by the fact that those units which succeed in reacting may be dotted here and there along the chains and may not reach the same stage of reaction simultaneously. Therefore it is usually preferable in determining the course of reaction between rubber and any particular reagent to make the early experiments with one-, two-, or six-unit rubbers, which are fortunately available, and then to compare the results with those obtained using rubber itself. Such experiments show that the individual rubber units absorb oxygen to form hydroperoxide groups which become attached to the chain at one or other of the three black **C** atoms in $\cdot CH_2 \cdot C(CH_3) : CH \cdot CH_2$. This means, selecting one (the most likely) of the three **C** atoms as representative, that a unit which reacts with a molecule of oxygen passes by some mechanism through the stages (*a*), (*b*) and (*c*), asterisks being used in the formulae to denote the radical centres:

$$\cdot\underset{\underset{H}{|}}{CH}\cdot C(CH_3) : CH \cdot CH_2 \cdot \xrightarrow{(a)} \cdot\underset{\underset{*}{|}}{CH}\cdot C(CH_3) : CH \cdot CH_2 \cdot \xrightarrow{(b)}$$

$$\cdot\underset{\underset{O\cdot O^*}{|}}{CH}\cdot C(CH_3) : CH \cdot CH_2 \cdot \xrightarrow{(c)} \cdot\underset{\underset{O\cdot OH}{|}}{CH}\cdot C(CH_3) : CH \cdot CH_2 \cdot$$

The questions then arise: How is the hydrogen atom lost or detached in stage (*a*)? Does an oxygen molecule help in its removal, or is its separation aided by light (or heat) alone? The questions have been difficult to answer conclusively. On the one hand, several workers have observed that the rate of oxidation of rubber and of other somewhat similar olefinic substances is independent of the oxygen concentration, and hence it might appear that the oxygen is not directly concerned in the first stage of the process. On the other hand, the severing of the C–H bond requires the expenditure of a considerable amount of energy which must be supplied from some source. Since, however, the oxidation of rubber proceeds most rapidly in sunlight or ultra-violet

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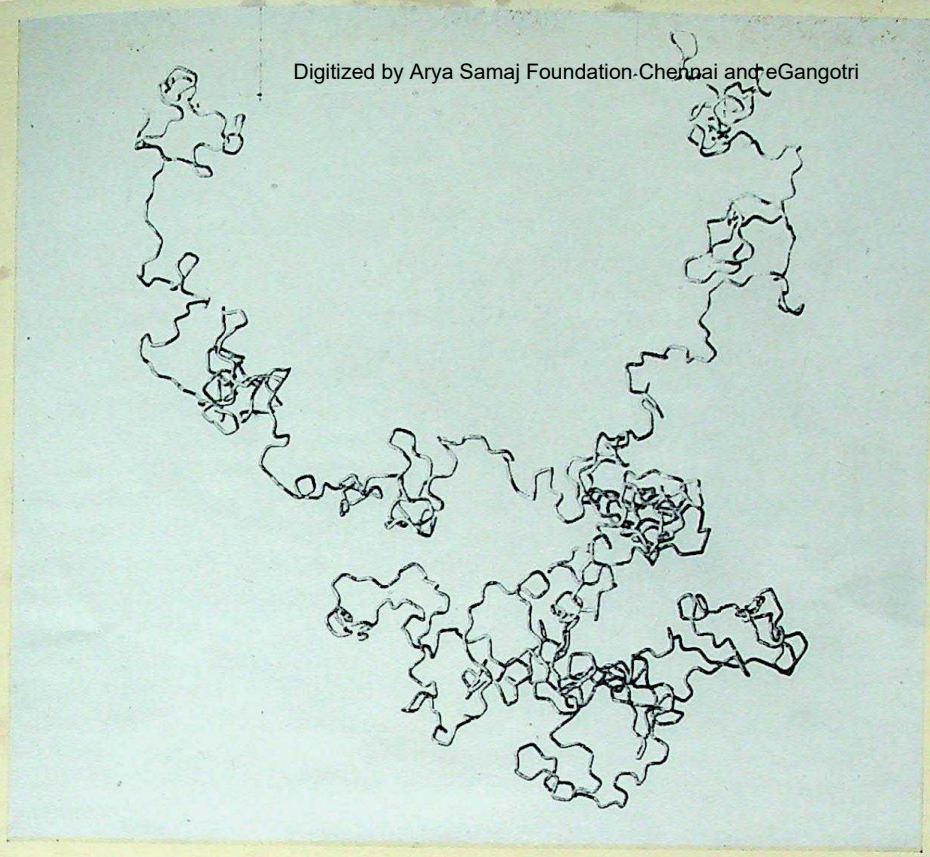

FIGURE 1 – *Treloar's large-scale model of a paraffin molecule of molecular weight* 14,000, *based on the statistical theory of Kuhn. The effect of random rotation about the* C–C *bonds is reproduced, the direction in space at each bend in the wire having been determined by the throw of a die. The distance between the ends proved to be about* 9 *in., a value very near to the theoretical value for the most probable length of this model molecule. The length when fully extended would be* 14 *ft., so that the extensibility of a* 1,000 *link paraffin molecule is about* 19 *times.*

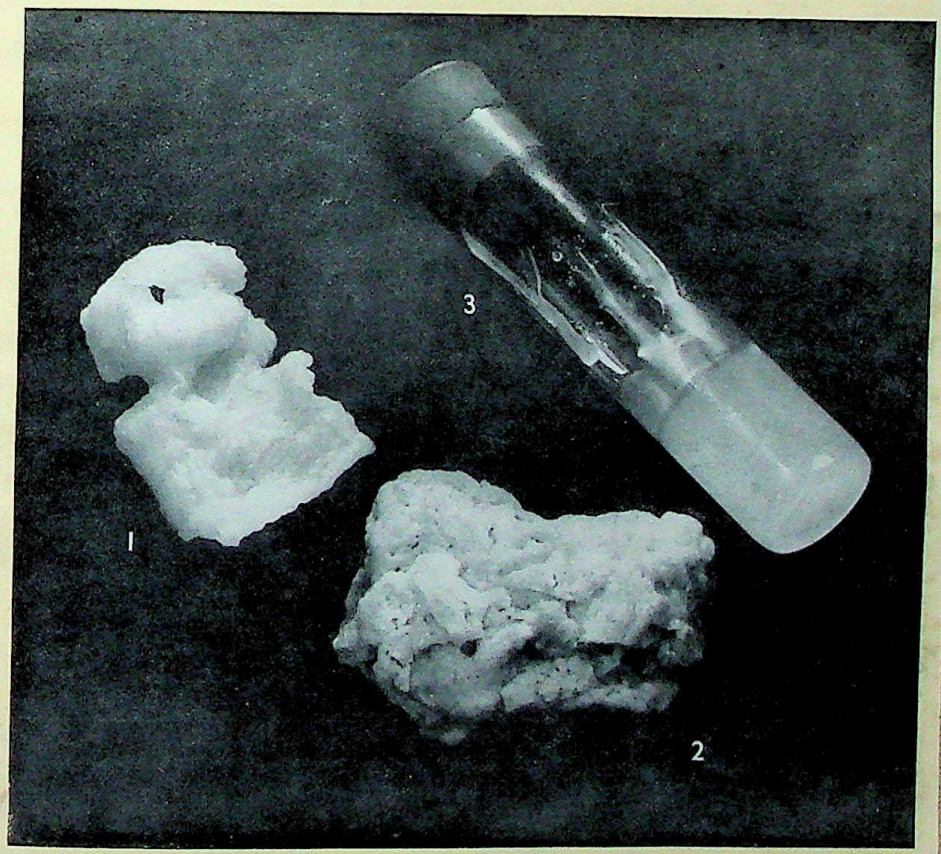

FIGURE 2 – *Hydrogenated rubber:* 1. *Complete hydrogenation. Slight cracking allowed to reduce reaction time (molecular weight* 150,000). 2. *Partial hydrogenation* (60%) *with slight cracking (molecular weight* 140,000). 3. *Complete hydrogenation with severer cracking (molecular weight* 49,000).

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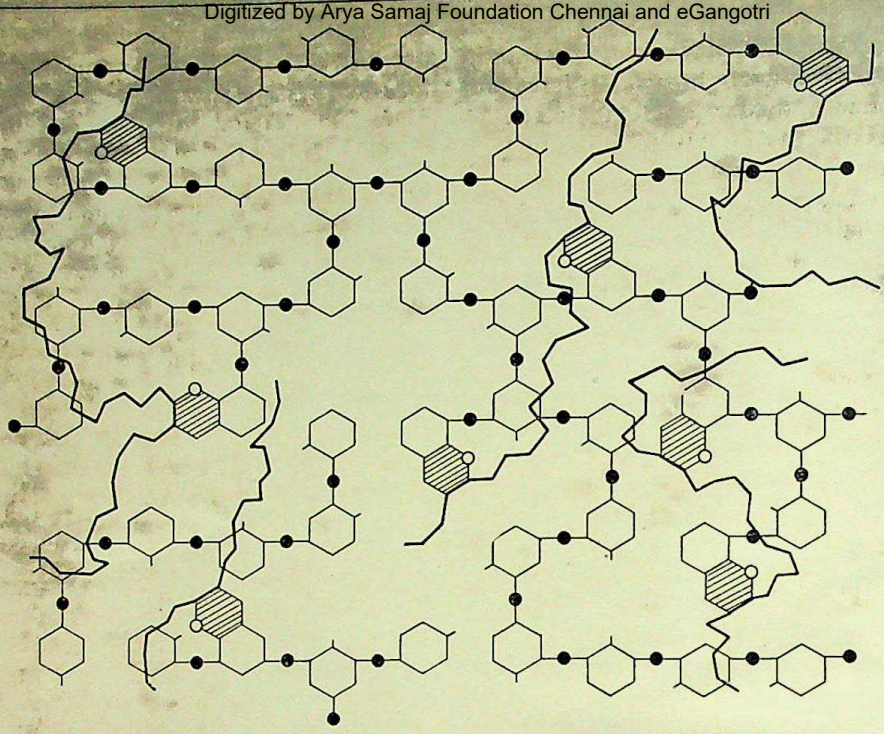
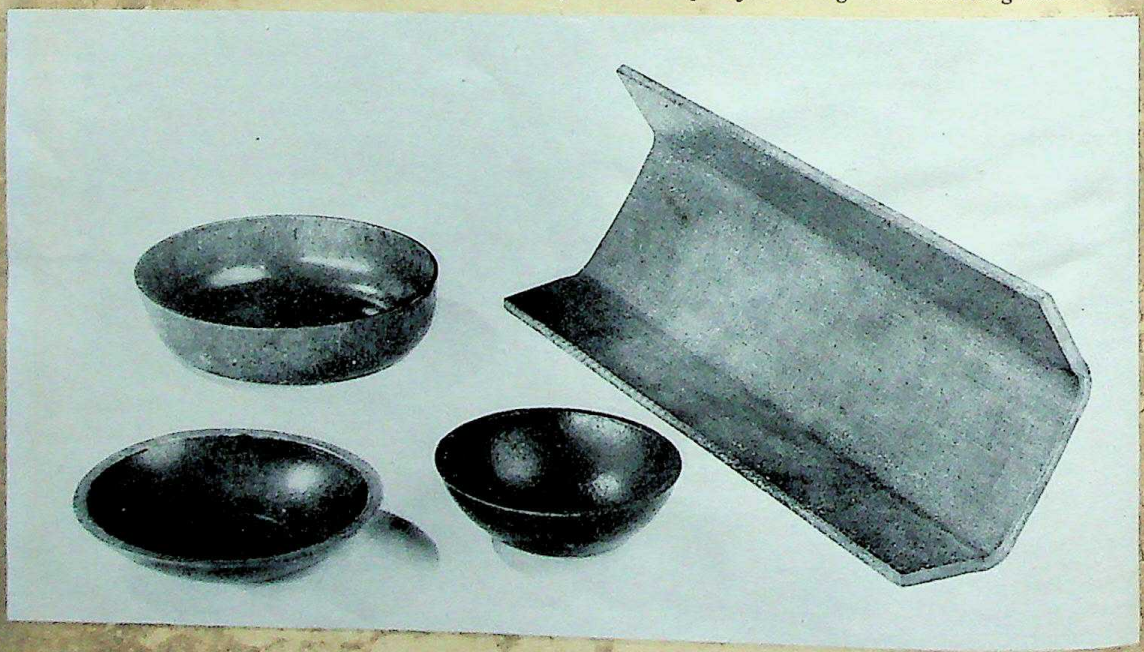


FIGURE 3 – *Conventional planar diagram of the three-dimensional molecular network in rubbone-phenol-formaldehyde resin. The black irregular lines represent rubber chains which effect junction with the phenol-formaldehyde network through the shaded oxygenated (chromane) rings. The unshaded hexagons represent phenol nuclei; their tails,* ·OH *groups; and the black dots* ·CH_2 *groups.*

FIGURE 4 – *Laminated boards of rubbone-phenol-formaldehyde resin reshaped after the original thermosetting had occurred.*



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light (i.e. under conditions which are known to favour the formation of neutral radicals from a variety of organic substances), it is reasonable to assume provisionally that the light-promoted oxidation at least involves the formation of radicals, and to pass on to view the consequences. It should, however, be noted in passing that rubber and similar polyolefinic substances undergo slow oxidation in the dark, i.e. thermal- as distinct from essentially photo-oxidation, and this phenomenon has been little investigated.

The correspondence of expectation with observed behaviour under the radical hypothesis is perhaps best seen in the case of methyl linolenate (derived from linseed oil) and the esters of various fish-oil acids which closely resemble methyl linolenate in structure [7]. These polyolefinic substances all undergo oxidation in air and light, like rubber, but have the double merit for the present purpose that the peroxides formed are much more stable than those of rubber and so do not confuse the issue by too early decomposition. Moreover, the arrangement of unsaturation in their carbon chains lends itself to the perception of structural changes more readily than does that of rubber. Methyl linolenate has the formula:

$$CH_3\cdot\underbrace{CH_2\cdot CH{:}CH\cdot CH_2\cdot CH{:}CH\cdot CH_2\cdot CH{:}CH\cdot CH_2}\cdot(CH_2)_6\cdot CO_2CH_3$$

in which the pairs of ethylenic carbon atoms are separated by only one methylene group instead of two as in rubber. Only the bracketed 10-carbon system need be considered. In this system the two CH_2 groups between the pairs of double bonds would be expected on general organic principles (and have, indeed, been found in practice) to be more readily susceptible to attack by reagents than the two outside CH_2 groups. If through irradiation of the ester in air the left-hand one of these CH_2 groups were temporarily to lose a hydrogen *atom*, with or without the assistance of a molecule of oxygen, then the resulting 10-carbon radical system (*A*) would contain two 3-carbon groups **1** and **2**, each one of which (alternatively) would be expected to fluctuate or resonate between the radical forms $\cdot CH{:}\overset{*}{C}H\cdot CH\cdot$ and $\cdot\overset{*}{C}H\cdot CH{:}CH\cdot$, until ultimately the missing hydrogen atom became replaced by another atom or group. Consequently the two radical forms (*B*) and (*C*) would be likely to appear immediately, in addition to the original form (*A*), and these would ultimately give, by collision with oxygen molecules followed by abstraction of hydrogen atoms from the surroundings, two different peroxido-molecules. Both these peroxido-molecules, however, unlike that similarly derived from (*A*), would display diene conjugation, i.e. they would have two of their double bonds alternating with single bonds—a condition which is easily recognized and measured by spectrographic means. Five additional peroxido-forms displaying diene conjugation, together with one showing triene conjugation, could arise if the right-hand CH_2 group, or the left- *and* right-hand CH_2 groups, together or in succession, lost hydrogen atoms. Therefore any serious degree of oxidation of the ester which involved radical formation could not fail to produce a considerable degree of diene conjugation and possibly a little triene conjugation. In practice it is found that when pure methyl linolenate absorbs one molecular proportion of oxygen in sunlight at room temperature (i.e. enough oxygen to attack every other CH_2 group) about one-third of the molecules show diene conjugation and 5 per cent. triene conjugation, and up to nearly the end of this absorption *all* the oxygen is present in the form of peroxide groups. Very similar results are obtained with the similarly constituted, but longer, unsaturated systems in the fish-oil esters; but with none of the esters can light, in the absence of oxygen, bring about any significant degree of conjugation. It seems necessary to conclude, therefore, that in ordinary oxidation-practice oxygen *is* directly concerned in the first stage of reaction, i.e. the formation of the organic radicals.

In the case of natural rubber or its low-molecular analogues the method of peroxide formation is similar to that in the esters. Here, however, the presence of *two* CH_2 groups between the ethylenic pairs of carbon atoms precludes the

(*A*) $$\cdot CH_2\cdot\overbrace{CH{:}CH\cdot\overbrace{CH\cdot CH{:}CH}^{1}}\cdot CH\cdot CH_2\cdot CH{:}CH\cdot CH_2\cdot$$

(*B*) $$\cdot CH_2\cdot\overset{*}{C}H\cdot CH{:}CH\cdot CH{:}CH\cdot CH_2\cdot CH{:}CH\cdot CH_2\cdot$$ (by resonance of **1**),

(*C*) $$\cdot CH_2\cdot CH{:}CH\cdot CH{:}CH\cdot\overset{*}{C}H\cdot CH_2\cdot CH{:}CH\cdot CH_2\cdot$$ (by resonance of **2**),

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possibility of any significant degree of conjugation occurring by the radical mechanism; and in addition the peroxide groups decompose swiftly after their formation, so tending to destroy unsaturation and to defeat observation. Consequently it is to be expected that no serious degree of conjugation will be observed in practice, an expectation which is realized experimentally.

Another well-known way of forming radicals from carbon compounds is that of heating them to high temperatures. With methyl linolenate and the fish-oil esters such formation occurs, in entire absence of oxygen [6], well below the cracking point, if the appearance of conjugation [15] is taken as a criterion. Here, however, the final degree of conjugation is small compared with that obtained by oxidation (< 5 per cent.), owing to the onset of polymerization among the conjugated forms. In the case of the rubbers, on the other hand, although radicals are doubtless formed, no conjugation appears on heating, and none would be expected in view of their constitution.

The formation of hydroperoxide groups as described above is only the first part of the oxidation process in rubber; for these groups readily decompose and act as veritable oxidizing agents for the material in which they occur [9]. The groups break down under the influence of light and of heat in a complex manner, the net effect being to oxidize the double bonds within reach, first oxygenating them (usually forming epoxy groups) and then severing them. In the early stages of oxidation a dozen or more oxygen molecules have to be absorbed to cause one complete break in the chain, but the process goes on steadily, with progressive shortening of the chains, even although only a few of the double bonds attacked are severed. Normally each ·OOH group retains half its oxygen as an ·OH group in the original position, and applies half to the oxidation of the chains. The process is exactly that which rubber technologists have used for many years to soften rubber. The rubber is kneaded in air between the rollers of a mill and so absorbs oxygen; its long chains are broken down by the oxidation to about one-third (on average) of their original length, so that the product is more tractable and more soluble. Of course, this convenient softening is effected by sacrificing in some degree those properties of toughness, resistance to mechanical shock, etc., which depend on the great length of the rubber chains. If the milling process is carried much further with the aid of a chemical oxidation catalyst, the rubber loses its solidity and a very useful material, 'Rubbone' [14], [16], [17], in which the rubber chains have been broken down to about one-ninetieth or less of their original length, is produced. The oxidation process, however, does not tend in all circumstances to reduction of the molecular size, because if the peroxide groups are decomposed at high temperature (e.g. on hot rollers), some of the chains or fragments become joined by oxygen links—mostly of ether type—to form heterogeneous chains.

DIVERSE COURSES IN CHLORINATION

Highly chlorinated rubbers prepared by the action of chlorine on rubber have been extensively used in the manufacture of acid-resisting paints, but the less heavily chlorinated rubbers are unstable. When chlorine reacts with rubber between −50° and + 80° C, the first molecule of reagent replaces a hydrogen atom of the rubber by chlorine, and the second largely does likewise. Only at the later stages of reaction does the chlorine begin to add at the double bonds. Indeed, it is necessary to resort to a stratagem to prepare the homogeneous additive dichloride $[\cdot CH_2\cdot C(CH_3)Cl\cdot CHCl\cdot CH_2\cdot]_n$, which is a relatively stable compound. The hydrogen atoms replaced by chlorine are found to be mainly those of methylene groups adjacent to the double bonds, but to a large extent cyclization accompanies halogenation. Thus two distinct types of substituted units are formed, $\cdot CHCl\cdot C(CH_3):CH\cdot CH_2\cdot$ and $\cdot CH\cdot C(CH_3):CH\cdot CH_2\cdot CH_2\cdot C(CH_3)\cdot CHCl\cdot CH_2\cdot$, both being very unstable and losing their chlorine completely by interaction with alcoholic silver nitrate [2]. The simplest and most coherent explanation of these facts is that both compounds are formed by direct displacement of hydrogen by the chlorine, which possibly involves radical reactivity. The additive reaction, too, is unlikely to be of ionic character.

RADICALS AND VULCANIZATION

The linking of rubber molecules to form immense insoluble complexes which occurs when rubber is heated with sulphur has long been thought to be an additive process in which sulphur acts simultaneously as an addendum for the double bonds and as a linking agent. The role of accelerators, however, in speeding up and often improving the vulcanization has not been understood. The simplest form of vulcanization is now recognized [5] to be that which is slowly effected by sunlight or ultra-violet light, and this can be

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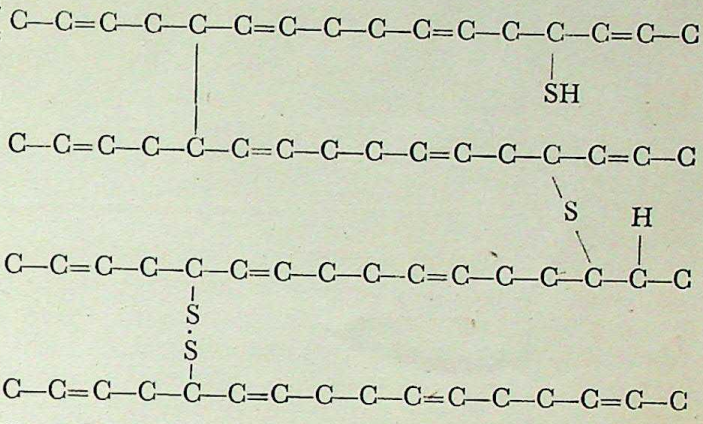
interpreted as resulting from the abstraction of hydrogen atoms (very slow compared with the rate of detachment of hydrogen atoms in oxidation processes) from the rubber chains by the light [1]. Any rubber molecule RH which loses one of its hydrogen atoms in this way forms an active radical R* which by collision with a neighbouring molecule can unite with the latter and expel a hydrogen atom ($R^* + RH \rightarrow R{\cdot}R + H^*$). The process can be continued either by the double molecule becoming a radical through loss of a hydrogen atom and then uniting with a third rubber molecule ($R{\cdot}R \rightarrow R{\cdot}R'^* + H^*$; $R{\cdot}R'^* + RH \rightarrow R{\cdot}R'{\cdot}R + H^*$), or by a third molecule of rubber becoming a radical and uniting with the double molecule ($RH \rightarrow R^* + H^*$; $R{\cdot}R + R^* \rightarrow R{\cdot}R'{\cdot}R + H^*$), and so on. The active hydrogen atoms expelled in the process can supplement the stock of radicals, which are formed so slowly by the action of light, and thereby help to keep the process going. A much more rapid reaction of the same kind can be brought about by adding to rubber an organic substance which itself breaks down into radicals. Such a substance is dibenzoyl peroxide [8], which gradually breaks down on being warmed, and doubtless some at least of the well-known accelerators owe their effectiveness to the same property. Usually, however, these organic materials in the process of contributing radicals add part of their substance to the rubber, thus chemically modifying it as well as cross-linking it. Sulphur achieves cross-linking at an early stage of its action on rubber [3]. Probably it owes its efficiency to its ability to detach hydrogen atoms from the rubber, so forming rubber radicals and thiol radicals ($RH + S \rightarrow R^* + HS^*$), the former of which would mostly become linked with neighbouring molecules by C–C bonds. The latter would either combine with, or extract hydrogen atoms from, adjacent rubber molecules, thereby forming (respectively) rubber radicals or hydrogen sulphide. In this way cross-linked structures such as that shown below would be formed.

The principle of vulcanization serves also in the linking of rubber with other molecules. Thus when dissolved rubber is warmed with maleic anhydride in presence of a source of radicals



(dibenzoyl peroxide), the radicals from the latter apparently detach hydrogen atoms from the rubber and so enable it to start combining with maleic anhydride. In this way technically interesting materials containing up to 1 molecule of the anhydride per rubber unit can be obtained. In other chemical processes, too, including the orderly thermal cracking of rubber, the formation of radicals from the rubber appears to play an important part. Sometimes, however, the ready formation of rubber radicals during reaction is an embarrassment, promoting cross-linking where the chemist merely desires to add reagents to the double bonds. In this case, premature vulcanization sets in, and instead of the normal, relatively soluble products expected highly insoluble ones are obtained.

In the past the remarkable physical properties of vulcanized rubber have made rubber one of the world's coveted basic materials: it seems likely that in the future the chemical versatility of rubber will afford means of extending its usefulness and thereby reinforcing its position in industry.

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The influence of hormones on man's social evolution

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S. ZUCKERMAN

Certain glands produce chemical substances, called hormones, which have a profound and vital effect on the functioning of the body. The processes of reproduction, for example, are completely dependent on changes produced by the sex-hormones. This article discusses, in general terms, the thesis that human evolution was related to changes in Man's sex-hormone physiology.

The story of human evolution is one of broad outline and little detail. A study of fossils shows that men possessing a skeleton identical with our own coexisted with somewhat different human types, as represented by Neanderthal man, in an early part of the present geological epoch, about half a million years ago. Beyond the fact that these other types died out, little else is known with certainty. How far back modern man reaches, and what his links were with extinct human types and with extinct and existing types of ape or monkey, remain unsettled questions. By what mutational changes we diverged from our parent types, and what selective processes ensured the perpetuation of these changes, are problems veiled in complete ignorance. In the circumstances, it is hardly surprising that theories of human evolution are still essentially broad and simple generalizations.

We do not yet know enough to do more than emphasize certain major factors that appear to have helped in the emergence of our species, and in the assumption of our present dominant position in relation to other forms of life on the globe. Most of these factors are unique characteristics in our biological make-up and modes of behaviour; unique in the sense that without them it is difficult to see how we could have achieved our present evolutionary position. In general, they fall into two groups—those which relate to our more recent human history and those which concern our prehuman development and emergence as man. Among the more prominent in the first group are our development of symbolic processes; the discovery of fire and of the wheel; and the slow coming together of animal husbandry, agriculture, and metal-working, to form a basis of the civilization we know today. These characteristics are so much a part of our life that it is difficult to realize that, in the time-scale of human evolution, they form a very recent acquisition. Figuratively speaking, they represent no more than the uppermost shoots of a tall and aged tree.

Our biologically unique characteristics enjoy a much greater antiquity. According to many authorities, the one which was most prominently concerned in our prehuman development, and without which we should not have evolved to the human level, is our dual possession of stereoscopic vision and fully opposable thumbs. This combination exists in no other animal. With it, the protohuman ape or monkey was able to explore and obtain increasing mastery over his external world, and because of the resulting interplay of tactile and visual impressions—so it has been argued—a simian brain finally evolved into the brain we possess. Compared with this, other biological characteristics that distinguish us from apes and monkeys are probably of small account. There is one, however, which was probably a critical factor during the period of our emergence as man. This is our unique diet. All apes and monkeys are predominantly, if not entirely, vegetarian. Man alone of the Primates is omnivorous.

If we had retained the Primate frugivorous habit, we should hardly have left the forests to which the gorilla, chimpanzee, orang, and gibbon are still confined by their dietary needs, and in the forests we should never have evolved as we have done. There is another side to this question. There is evidence that the forests of our forebears disappeared during a geological period of aridity, in the course of which it is believed we underwent the critical changes from an ape-like to a human form. It is not unlikely, therefore, that an omnivorous habit was actually forced on our ancestors by the gradual shrinkage of their natural food reserves, only those ape-men surviving and perpetuating themselves who succeeded in becoming adapted to a partly carnivorous diet—such as the cave-men of yesterday

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enjoyed, and such as would enjoy. Whatever way the change occurred, it is not difficult to see that it must also have been associated with major readjustments in family and social life.

The social unit in old-world monkeys and apes, and by inference presumably in the world of our forebears, is generally a polygynous and non-promiscuous family group which holds together as long as its male overlord remains sufficiently dominant to keep other males from, and to impress his own company on, his females. Internal familial relationships are largely determined by the sexual rhythms of the females, their alternating heat periods determining which is the favourite wife for the moment. Young can be born at any time of the year, but, so far as we can tell, the frequency of births shows marked seasonal variations. The family party grazes together, male, females, and young, all picking their own roots or fruits.

Familial relationships of this kind do not fit into a hunting economy, or a mixed hunting and food-gathering economy, of the type early man had to assume. Such an economy necessitates the sexual division of labour, since nursing and pregnant females and young could hardly join in the chase. With little doubt they would have stayed behind, collecting what roots and fruits grew around their homes, while their males hunted. Here, one is forced to another conclusion. Such a food economy is also hardly compatible with a polygyny sustained by male dominance. Since the sex ratio is to all effects equal, every polygynous unit means a number of roving unattached males waiting for the chance to break up a family when its overlord is away hunting. Slowly, natural selection must have worked on the conflict between sexual and nutritional drives, and monogamy must have become established as a disciplined habit of food-gathering and hunting peoples—as it remains today, so it is stated, among those of them who still survive in scattered parts of the world. If polygyny had continued through this phase of human history, it is difficult to see how the proto-human species could have avoided extinction through continuous familial disruption and internecine strife.

The topics that have been discussed so far are major issues in the story of our development which, at one time or another, have already excited the interest of students of human biology. In one sense, as has been suggested, they are no more than inferences from points of difference between us and the rest of the animal world. And, in another, they are no more than the statement of positive factors to which we can relate either the whole or part of our unique evolutionary development. None of them applies to the rest of the mammalian group to which we belong, and conversely it is difficult to recognize any characteristics peculiar to apes and monkeys which, had we possessed them, would have accelerated our own evolution. Indeed, in the more important biological equipment we improve on them every time. For example, our brains are basically—from the anatomical point of view—no different from theirs, but are very much better developed. Our hands are essentially the same, but being less evolved in certain directions, are more flexible in use. Our feet may be more specialized structures, and of no use as an accessory pair of hands, but conversely they are adapted to an upright attitude, which permitted the complete emancipation of our fore-limbs from their previous function as supporting and locomotor organs.

If it is difficult to recognize any sub-human Primate characteristics which would have accelerated our evolution, it is simple to see some which might have acted as obstacles to our development. Thus, there is one major difference of a negative kind between us and the rest of the zoological group to which we belong, and we can now see that this was probably as important to our evolution as any of the factors which have already been touched upon. It is our freedom from the rigorous internal chemical control of reproductive functions such as is experienced by apes and monkeys and even more so by other mammals. Recent research into the physiology and chemistry of the hormones which control reproduction—the hormones of the anterior lobe of the pituitary gland, and the steroid hormones of the gonads—shows that this freedom must have been vital to our emergence as *Homo sapiens*. Let us look at the question more closely.

The rhythm of life in most wild animals is rigidly fixed by the periodicity of the reproductive processes. Thus, the migration of birds is ruled by fluctuations in the bodily concentrations of the steroidal hormones produced in the gonads, and these fluctuations are, in turn, determined by seasonal variations in the degree to which light stimulates the anterior lobe of the pituitary gland to produce its gonad-stimulating hormones. If a bird which is about to set out on its southward flight as the autumn approaches is caged for a sufficient period for its reproductive organs to

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regress to the non-breeding state, it will make no attempt to migrate when it is released. The motivating power, or drive, provided by its sex-hormones is no longer there.

Similarly, the entire life of most mammals is constrained by the periodic functioning of the sex organs. Thus, while the geographical areas in which most wild mammals are found are fixed by general selective processes, for example nutritional needs, their major movements within these areas are directed by the internal motivating forces, if they can so be called, which vary according to fluctuations in, and changes in the nature of, the sex-hormone content of their bodies. Thus the fighting of stags in the early autumn; their subsequent mating with the hinds; the formation of polygynous family parties sustained by male dominance; the breaking away of the unmated males; and, when the mating season is over, the separation of males and females until next year's season approaches, depend for their motivation entirely on these sex-hormones. The worlds of such animals, already restricted to their immediate environment and immediate present, are thus rigidly determined by an internal chemical control, whose bonds cannot be broken. What they do next, and their social relationships, are both preordained.

This internal chemical control is not as strict in the world of apes and monkeys, but, so far as is known, it is still sufficiently powerful to dominate the social lives of almost all species. As in the case of the Red Deer, the geographical areas in which monkeys and apes live are determined by general selective processes. On the other hand, although their birth-rate shows marked seasonal variations, sexual activity is not confined to a restricted season, and consequently male and female monkeys and apes are always together. Their social unit, however, as has already been mentioned, remains in general the polygynous family party sustained by masculine dominance. This can be taken as representing the operation of a powerful masculine sex-drive—a drive at least partly determined by the concentration of male hormones in the body. Furthermore, relationships of the females to the males within each family unit, and of the females to each other, are controlled by the alternating periods of heat of the females. These reflect phases of elaboration and concentration of gonadal sterol hormones, and in many species are associated with very prominent changes in the appearance of the body. A female in heat appears to dominate masculine interest and, at the same time, is very strongly attracted to the male. Her sexual dominance affects all members of the family party of which she is a member. In this way, a rigid chemical control of social relationships delimits the bisexual social world of the ape or monkey.

From all this man has been freed. Had so rigid a mechanism operated in the period of our emergence, the proto-men could hardly have undergone either the ecological change in food habit which ensured human survival or, what we may now be permitted to regard as the first major social revolution of our species, the stabilization of the family unit. The inference that such a change must have occurred suggests that the motivation provided by male sex hormones was not strong enough to prevent the first men from abandoning, at least overtly, the full exercise of polygynous tendencies. Furthermore, it is a safe assumption that the rhythm of sexual impulse was probably very much weaker in the first women of our species than it is in existing apes or monkeys, or than it probably was in our ape-like forebears. Had these things been otherwise, personal relationships would have been too confined by internal chemical control to permit the social changes necessary to our survival and social evolution.

But very obviously they were not confined. Instead, by means of the symbolic processes we have developed, we have been able to reach out to a mastery of our external world, a mastery extending far beyond the confines of our immediate environment, and a mastery which also frees us completely from the confines of a restricted geographical orbit. But in our freedom from a predetermined and hormone-determined framework of social relationships, we are at a disadvantage in other ways, in particular because of our failure to come to any agreement about the shape human relationships should take. Major differences of opinion on this problem have resulted before, and now result once again in this war, in violent intraspecific struggles. If the major biological steps in our social evolution have been correctly read, similar struggles had to be overcome at another very dangerous period of our evolution, the time of our emergence from the ape world.

Another disadvantage of our relative freedom from sex-hormone control has a more individual character. The association of human evolution with the abolition of a clockwork reproductive system finds us today in possession of a system

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which, quite apart from the fact that it can be very easily checked by individuals anxious not to breed, not uncommonly breaks down physiologically.

For lack of evidence to the contrary, the decline in the birth-rate which is now occurring in most countries is not generally ascribed, either in part or as a whole, to physiological causes—although it can of course be said that were the internal chemical control of human reproduction stronger and more clock-like in its action, it would be more difficult to check reproduction than in fact it is. The general problem is, however, so important that the possibility that physiological factors do help in producing today's widespread picture of sterility urgently requires investigation. Associated with such an inquiry we also need more intensive research into the physiology and chemistry of the endocrine system in general, and of the sex-hormones in particular. Quite apart from the wider problem of population growth and decline, only such research can help the more easily recognized cases where the human reproductive machine breaks down for definitely physiological reasons. We might almost say that, if the emergence of man was related to a partial emancipation from a predetermined control exercised by these hormones, the well-being of its future will undoubtedly be assisted by a rational control of reproductive and endocrine derangements. For this, much more knowledge is wanted than we yet possess.

Book reviews

DETECTION OF RADIO FAULTS

Testing Radio Sets, *by J. H. Reyner. Pp. viii + 215. Chapman & Hall Limited, London. Fourth edition, revised,* 1943. 15*s. net.*

In testing a radio set an orderly approach to the task is essential, but slavish adherence to a routine will often result in an effect passing unnoticed or, at least, remaining undetected until many of the tests have been repeated. The author of this excellent book pays due attention to instilling an appreciation of the principles underlying the various tests.

Just sufficient of the functioning of the circuits and components is explained to make performance-checking and fault-finding a process of straightforward deduction, as far as is possible with the wide variety of designs which is likely to be met.

A useful feature is the treatment of variations in design, with special reference to their effect on irregular behaviour of equipment. The beginner will find the hints on the best arrangements for wiring worthy of attention.

The chapter on unusual faults leaves the reader in the right frame of mind to do some real detection when normal methods fail to reveal the cause of the trouble.

Anyone requiring guidance in testing radio sets will find Mr Reyner's book most valuable. It is characterized by clarity of explanation and a minimum of mathematics.

WEATHER WISDOM

The Weather, *by George Kimble and Raymond Bush. (A Pelican Book.) Pp.* 188. *Penguin Books Limited, Harmondsworth and New York.* 1943. 9*d. net.*

It is not an easy task to present a highly technical subject in a way that will appeal to the ordinary reader, but the authors of this book may fairly claim to have achieved it. Within its 188 pages there is a wealth of information about weather phenomena, all very simply expressed; and the reader who is of an inquiring turn of mind will find lucid explanations of the physical processes which underlie the changes in our weather.

The numerous references to weather lore are particularly interesting, and the authors are able to show that the 'Shepherd of Banbury' is frequently supported by both fact and theory; on the other hand, they condemn in no uncertain terms such apocryphal instruments as the 'storm glass' and astrological portents like 'the moon lying on her back.'

It is to be hoped that readers who follow the suggestion of becoming their own single-observer forecasters will not expect too high a proportion of successes. Subject to this proviso, there is much to be said for the idea. The making of your own observations is in itself an excellent habit, whilst the failure of even the most confident of your own forecasts may make you a trifle less critical of the professional forecaster's lapses! N. K. JOHNSON

A SURVEY OF INORGANIC CHEMISTRY

Inorganic Chemistry, *by Fritz Ephraim. English edition by P. C. L. Thorne and E. R. Roberts. Fourth edition. Pp. xii +* 921. *Gurney & Jackson, London.* 1943. 28*s. net.*

The progress of inorganic chemistry is epitomized in a comparison of the four editions of this book. Unique among textbooks of inorganic chemistry in its conception and planning, the first edition in 1926 went far in its attempt to present an adequate and at the same time coherent survey of the facts of inorganic chemistry. Since that date the rapid progress in knowledge of atomic structure and the development of clearer ideas of the nature of atomic bonds have made possible a more compact and logical treatment of the chemistry of inorganic compounds.

This progress is reflected in the changes that have been made in the earlier parts of this edition, and the reviewer finds in the first three chapters an admirable and concise summary of present knowledge of atomic structure, of valency theory, and of methods of determining molecular structure.

The remaining chapters of the book have been fully revised in the light of this knowledge, and wide use is made of the more intimate picture of molecular structure provided by X-ray crystal studies, by electron diffraction, and by dipole moment measurements.

In revising the factual matter,

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judicious selection has been shown in the accounts of recent work that have been included, and the gain in material has been achieved without sacrifice of the essential cohesion of the treatment. Every student of chemistry will find this new edition helpful and stimulating; its production is a triumph in war-time conditions. No other book, within such a compass, presents so satisfactory a survey of the field.

F. G. TRYHORN

FAT METABOLISM IN ANIMALS

The Metabolism of Fat, *by Ida Smedley-MacLean. Pp. vi + 104. Methuen & Company Limited, London.* 1943. 4*s. net.*

This excellent little book gives a summary of present knowledge concerning fat metabolism in animals and in isolated animal tissues. It is most useful for both student and teacher, and is supplied with an adequate number of references to the most significant literature. Results of modern methods of attack on the problems of fat metabolism, such as those obtained with the use of radioactive phosphorus or heavy hydrogen, or with the employment of the tissue-slice technique, are discussed. Chapters in the book are devoted to the subjects of the mode of synthesis of fatty acids in the body, of the constitution of the natural polyene unsaturated acids and the part they play in fat metabolism, of the modes of combination of fatty acids in the body, of the methods of absorption and transport of fats in the body, and of the modes of fatty acid oxidations. The book is well written and the subject-matter is critically presented.

J. H. QUASTEL

IDENTIFICATION OF DISEASE-BEARING INSECTS

A Handbook for the Identification of Insects of Medical Importance, *by John Smart and others. Pp. x + 270, with 13 plates. British Museum, London.* 1943. 15*s. net.*

Few aspects of animal biology have shown more rapid growth than medical entomology. From the zoological standpoint new knowledge is continually being added concerning the species of insects that are vectors of disease. At the same time, medical workers are adding to the fund of information bearing on the pathogenic agents concerned and on methods of preventing or curing their effects. It is rarely that these two aspects of a great subject are adequately combined in a single textbook, and the rapid growth of medical entomology renders this synthesis increasingly difficult to attain. Dr Smart's volume is essentially a zoological treatise. It is concerned with the identification of all Old World species of insects known to be of significance in medicine and hygiene. The importance of accurate identifications is paramount, for one species of insect may be a proven disease vector and a closely allied species may be totally harmless. Wrong identification of a species of *Anopheles*, for example, is likely to render attempts at malaria-control unavailing. In the literature of medical entomology there are numerous cases of misidentification. In the present book only an elementary knowledge of entomology is assumed, but we anticipate that little difficulty will be found in following its tables and descriptions. These are clearly drawn up and accompanied by an excellent series of illustrations. In a work of this kind the Diptera naturally call for the most extended treatment. In addition to keys for the identification of the adults, there are useful synopses for the recognition of myiasis-producing larvae and of the fourth-stage larvae of *Anopheles* affecting different regions of the world. The Siphonaptera, or fleas, come in for very full treatment by Dr Karl Jordan, and Mr R. J. Whittick contributes a useful chapter on Arachnida. The authors and the Trustees of the British Museum are to be congratulated on having produced a thoroughly sound and up-to-date volume. Its exceptionally low price, as judged by present-day standards, is a further commendation.

A. D. IMMS

THE OUTLOOK FOR WOOL PRODUCTION

The Future of Wool, *by Pablo Link. Buenos Aires.* 1943. *N.p.*

An analytical survey of wool production in the Argentine illustrated by details of the wool and sheep production in the different provinces. Since 1895 there has been a steady increase in numbers of sheep in Patagonia, while individual fleece-weights have increased from 6 lb. to 8¼ lb. The wool consists mainly of fine to coarse crossbred types. An attempt is made to forcast the future of wool in post-war years by considering the trends in the textile industry. While the consumption of some textiles has increased more than that of others during the last thirty years, the *per capita* consumption of wool has increased by 20 per cent. Because of the difficulty of producing artificially a cellular tube which felts like wool, it is considered unlikely that the synthetic wools which have been produced will be suitable for cold climates. It is concluded that both cotton and wool have increased, and will increase, in consumption without interfering with one another. There has been a decrease, and as a result of the war there will be a further reduction, in European wool production, so that wool in large quantities will be required in the future.

PETROLOGY OF IGNEOUS ROCKS

Eruptive Rocks, their Genesis, Composition, and Classification, *by S. J. Shand. Pp. xvi + 444, with 3 plates. Thomas Murby & Company, London; John Wiley & Sons Inc., New York.* 1943. 25*s. net.*

The appearance of the second edition of Professor Shand's stimulating textbook will be welcomed by many geologists. The book was first published in 1927, and opportunity has been taken to make a complete revision and to add more than 80 pages. This has made it possible to include new chapters on the order of crystallization of minerals, compatible and incompatible phases, and eruptive rock complexes, but in addition there is a much more extensive discussion of recent petrological literature. A wide range of references following each chapter is a valuable feature of the book.

The account of the physical chemistry of the igneous rocks presents the more important aspects of the subject in such a way that it will form a suitable introduction to this subject for other readers whose main interest in not in petrology. After a discussion of the problems of classification, eight subsequent chapters are devoted to the more detailed description of the igneous rocks. The final chapter deals with meteorites, and leads to the consideration of the 'pregeologic' history of the earth.

The volume is well illustrated, splendidly produced and, apart from some delay in its publication, does not appear to have suffered seriously from war-time conditions.

A. E. TRUEMAN

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ENDEAVOUR
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A quarterly review designed to record the progress of the sciences in the service of mankind

VOLUME III JULY 1944 NUMBER II

Science and the film

In this number we publish an article based on a film recently taken at a London hospital. This film marks a notable step forward in the application of cinematography to the needs of science. It records the movements of the tongue in human speech, and is the first record of such movements by the film camera. The film is therefore important, not only as a matter of scientific interest, but as of direct assistance to speech therapy. It has been welcomed particularly by the Royal Air Force as a contribution towards the rehabilitation of flying men with facial injuries who have virtually to be taught to speak again.

There is still a tendency in scientific circles to regard the film as a method of public entertainment, and thence to assume that films other than those of a dramatic character are not tolerated unless served up in a manner which demands no conscious mental effort and therefore leaves no worth-while impression. If such an assumption is true, it represents one of the defects of modern culture which science is concerned to remedy. It is a call for action. It is, however, doubtful if the generalization is entirely correct. There is abundant evidence that a proportion of the cinema-going public, though perhaps not a very large proportion, does welcome the informative type of film; and that the more intelligent cinema owners recognize the need to include in their programmes a percentage of films which 'appeal to the intelligence instead of assault the emotions.' Unfortunately, through the activity of the publicity man, this type of film has tended to become suspect. It has too often been made a camouflage vehicle for propaganda or advertisement. Yet the success of documentary films such as the world-famous British 'Secrets of Nature' should leave no doubt that an important place might and ought to be found, even in public entertainment, for informative or instructional films. The trouble is that no serious attempt has yet been made to produce scientific films in sufficient quantity, or simple and attractive enough to be understood without undue effort by members of the general public.

Realization that the film is a powerful agent for the exposition of science has quickened only within the last few years. It has received a great stimulus during the war, when there has been need to warn or instruct the services or the public on points of tactics, safety, and well-being. A most encouraging sign is the way in which scientific film associations have bred and mustered. In Great Britain there are today nearly 100 such associations, and these have recently come together in a single national association. The value of such a society is not least in the inducement it offers to those willing to sponsor scientific films. It gives them assurance that the films they make will be seen by large audiences of persons with greater intelligence than the average likely to be found in the entertainment theatre. As to what constitutes a 'scientific' film, we may subscribe to the generously framed definition which describes as scientific 'any film which (*a*) presents phenomena or events objectively for observation or study; (*b*) investigates, presents or explains phenomena or events in a way which shows them to be part of a rational coherent whole; and (*c*) shows that such investigation, presentation, or explanation as a method of looking at reality can be used by anyone and can enable him to live more fully.'

It was once remarked by an able lecturer that the secret of success in lecturing was to assume that the audience had no previous knowledge of the subject. Something of the same assumption is necessary if scientific films are to be successfully devised for audiences of the general public. The quantity of information offered must be prudently regulated, and it cannot be too often reiterated that there is only room for one single message in

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each film. Provided that this one message is assimilated by a reasonably large proportion of the audience, the film can be regarded as a success. A difficulty is that scientific men who interest themselves in film production may fail to recognize the extent to which scientific terms and images are foreign to the minds of the ordinary citizen. It should be emphasized that it is not sufficient to make the ordinary man and woman appreciate that science 'can do something' for them. There is the larger object of familiarizing the community with scientific methods and of imbuing it with the spirit of science. The film, more rapidly and surely than almost any other vehicle, could help to achieve this aim if used with imagination and insight. Perhaps it will have less direct effect upon the older generation, whose minds are already past the stage of receptivity, but the future is with the young, and there is no doubt of the power of the film to open the doors to a new world for children and adolescents. Even with the young generation, however, there are problems. We know with increasing precision what can and what cannot be done with pedagogic films, and there is every indication that educational organizations are alive to the great possibilities which await the film for teaching purposes after the war. Enthusiasm, however, may become uncritical, a danger that is perhaps more likely to affect scientific than other subjects which the film may be used to teach. Science teachers will have to face the responsibility of deciding what type of films they require, and this is not a matter which can be settled out of hand. It will need the production of preliminary experimental films, designed by science teachers in collaboration with film technicians, and followed by educational research, in which the films are tested in a variety of schools and by a variety of methods. Until a fairly extensive scheme of research along these lines has been carried out, those charged with the duty of teaching science to children would seem well advised to adopt a cautious attitude towards the spate of films that may be expected on the return of peace. Quite apart from this, there will be the need to train teachers in the appropriate technique—psychological as well as manipulative.

In colleges and universities the film will be valuable in research as well as in education. Records of natural processes, such as the speech therapy film already referred to, and of experimental demonstrations, constitute an excellent method of putting students into close touch with the realities of their subject and of keeping them abreast of developments as they occur. The film can also serve to demonstrate laboratory experiments on an industrial scale, and thus to stimulate the student's interest by showing him that work which may seem to him purely academic, or even dull, has a definite and practical application in the realm of production.

In research, the film has already well proved its worth, particularly in the study of the dynamics of living matter. As a permanently recording medium, it enables transient phenomena to be studied and analysed without haste; and by accelerating or retarding the record fuller comprehension of a continuous process is often obtainable than could be derived in any other way. Among the problems successfully investigated by cinematography or cinematomicrophotography are the course of the circulating blood in the living foetus within the mother, and the fertilization and early development of the living mammalian ovum *in vitro*. It is fitting that the film should be so efficient a servant of biology, for, as Dr Pijper has recently recalled, filming had its origin in biological curiosity: the desire to know whether a galloping horse ever has all four feet off the ground at the same time. This was in 1872, when the American Muybridge made a galloping horse photograph itself in a succession of twenty-four cameras by means of wires stretched to the shutters. In this work there were the 'two elements that make a film: analysis by a rapid succession of photographic pictures, and a suitable synthesis of the pictures on a screen.'

One thing is certain—that the encouragement of the film is of great direct, and of greater indirect, importance to science. At the moment and in most countries the production of films by private individuals or undertakings is necessarily subject to extreme limitations; but it is not too soon to examine the problem. Exploratory work carried out now will facilitate production when peace returns to the world.

Contributions and correspondence should be sent to the editor: E. J. Holmyard, M.A., M.Sc., D.Litt., F.R.I.C., Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1. Scientists engaged in research of an interesting or important character are invited to send short notes on work in progress and results obtained.

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Climate, weather, and man

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DAVID BRUNT

Is it by chance that the early civilizations arose on or near the isotherm of annual mean temperature 70° F? Is it significant that the glories of the Tudor period in England came so soon after the general use of coal for heating? Professor Brunt has interesting suggestions to make on these and other questions, and indicates also that the white man's reactions to hot climates promise to be important in post-war settlement and therefore deserve close study.

SOME REACTIONS OF THE HUMAN BODY TO ATMOSPHERIC CONDITIONS

The human body works best when its internal temperature is about 98° F, and any marked deviation from this temperature leads to discomfort, and in extreme cases to death. Heat is produced within the body by the process of digestion and by muscular effort, and must be dissipated from the body as fast as it is generated, if equilibrium of body temperature is to be maintained. The body can, however, maintain approximate equilibrium under a wide variety of external conditions, and a man shivering with cold on a winter's day will have almost the same internal body temperature as on a summer day with the sweat dripping from his forehead.

The heat generated within the body is conducted to the skin, largely by the blood circulation, and is dissipated from the skin by radiation, convective air motion, and the evaporation of perspiration. In a cold environment the surface blood-vessels contract, so that the conduction of heat to the skin is checked, while the loss of heat from the skin to the environment is to some extent minimized by the cooling of the skin. At a certain stage of body cooling there is an onset of shivering, which is an attempt to increase heat-production by muscular movement. Gooseflesh, an involuntary raising of the hairs on the body, each by a tiny muscle, is an effort to retain as deep a layer as possible of warm air in contact with the skin. At low temperatures, the internal generation of heat in the body is accelerated by the discharge of fluids from the thyroid and adrenal glands into the blood-stream.

In a hot environment, or during physical effort, a new mode of heat regulation comes into operation. The sweat-glands become active and discharge water on to the surface of the skin, from which it evaporates, and in so doing removes heat from the skin. As the temperature of the environment rises, the rate of sweating increases, until a stage is reached at which sweat drips from the body. If the body temperature continues to rise, in spite of the loss of heat by the evaporation of sweat, the blood-pressure falls, the pulse-rate increases, and strong palpitation is felt, followed by a condition of stupor which ends in death by heat-stroke.

In a clothed man reclining indoors, the sweat-glands do not become active until the temperature of the environment has reached about 29° C (84° F). At temperatures below this limit there is an insensible loss of water, as vapour, through the skin and from the walls of the lungs. The cutaneous insensible perspiration does not pass through the sweat-glands, except on the palms of the hands and the soles of the feet; it does not wet the skin. It varies considerably in different persons, and is usually stated to be from $\frac{1}{30}$ to $\frac{1}{18}$ pint per hour, or about $\frac{4}{5}$ to $1\frac{1}{2}$ pints per day. The active secretion of sweat is at a much higher rate, and may be as much as 9 pints per hour during an energetic game of football.

The temperature of the skin varies over different parts of the body, and in a cold environment is lowest over the feet, next lowest over the hands, and highest over the head. The extremities are the coldest parts of the body, the trunk being less affected by low temperature of the environment. The wearing of sufficient clothing will maintain the skin temperature over the trunk at a high level, but the extremities require special protection in a cold environment. This emphasizes the need for care in the design of gloves and boots for men exposed to low temperatures.

THE HEAT ECONOMY OF THE BODY INDOORS

The processes of oxidation of body tissues, in the course of digestion or of physical effort, are grouped under the term *metabolism*, and the rate of

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generation of heat in the body by the metabolic rate. There are three processes of removal of heat from the body. Heat will be carried by the air (by convection) to or from the body, according as the environment is warmer or colder than the skin. The body will gain or lose heat by radiation to and from surrounding objects, walls, etc., according as the radiating parts of the environment are warmer or colder than the skin. Further, heat is constantly being lost by the evaporation of perspiration from the skin and of water from the walls of the lungs. The body may suffer a net loss of heat and become cooler, or may suffer a net gain of heat and become warmer. The net rate of loss of heat from the body is called *storage*, and is treated as negative when the body heat-content increases.

The sum of the metabolic rate and the storage rate must be equal to the sum of the three rates of loss—by evaporation, by radiation, and by convection. The metabolic rate is measured by the oxygen–carbon dioxide exchange of the body. The rate of loss of heat by evaporation is deduced from the loss of weight of the body. The rate of storage is deduced from the change in the mean temperature of the body, the specific heat of the body being taken as 0·83. It is then possible to compute the rate of loss of heat by radiation and convection.

The experimental data referred to below were accumulated, in the course of a long series of experiments, at the John B. Pierce Laboratory of Hygiene, Newhaven, Conn., by the Director of the Laboratory (Dr C. E. A. Winslow), Dr L. P. Herrington, and Dr A. P. Gagge. The subjects of the experiments were placed in a specially constructed booth, in which temperature, humidity, and air movement could be controlled, while the radiation from the walls could be controlled by specially reflecting or heating devices in the walls. The balance used for weighing the subjects was sensitive to 2 grams, about $\frac{1}{17}$ oz.

As clothing is a complication which tends to mask the essential physiological processes involved, the earlier experiments were usually made on nude subjects, but later experiments were made with clothed subjects. The clothing worn consisted of a two-piece suit of cotton underwear, a cotton shirt without ties, socks, low leather shoes, and a grey suit with three-quarter lined coat and fully lined vest. The air movement was restricted to 17 ft. per minute.

A series of experiments on subjects so clothed, and reclining indoors, is summarized in figure 1. Here the unit in which the rates of exchange are given is 1 kg-cal. per square metre of skin surface per hour. The operative temperature which is plotted in the diagram is a weighted mean of the temperature of the air and walls, estimated to give a representation of the joint effect of radiation and convection, and it is only the sum of these two items which is shown in the diagram. The operative temperature is equal to the air temperature when the air and the effective radiating surfaces are at the same temperature.

The metabolic rate, as shown in figure 1, varies little with temperature, though there is a definite rise at the lowest temperatures. At all operative temperatures up to 29° C the evaporative loss is the combined effect of evaporation in the lungs and of the loss of insensible perspiration through the skin. At temperatures above 29° C the evaporative loss is mainly due to the evaporation of sweat discharged through the sweat-glands, and in a hot environment it is this evaporative loss which exercises the essential control over body-heat. At low air temperatures the essential control over heat loss is by the joint effect of radiation and convection, but at the highest temperatures shown in the diagram these two factors yield a small gain of heat by the body, a gain which can become important when the air movement is high. The curve for storage shows that in an environmental temperature below about 25·5° C the body loses heat, and cools. Thus we may define a zone of body cooling from 25·5° C downward, and a zone of evaporative control from 29° C upward. In the intermediate zone from 25·5° C to 29° C there is neither body cooling nor active secretion of sweat, and the equilibrium of the body is maintained by the control of the flow of heat from the inner parts of the body through the dilation or contraction of the surface blood-vessels. This intermediate zone is known as the zone of vasomotor control.

In figure 2 are shown, for nude subjects, values of the mean skin temperatures, of the wetted area of the skin, and of the conductance of the body for a similar range of temperatures to that of figure 1. In the zone of evaporative control the skin temperature is independent of operative temperature, except for a slight rise at operative temperatures above 37° C. At all temperatures below 31° C the skin temperature falls off by about 1° for every 2° fall of operative temperature.

W, as shown in the diagram, is a measure, in arbitrary units, of the area from which evaporation takes place. It is seen that **W** rises steadily as

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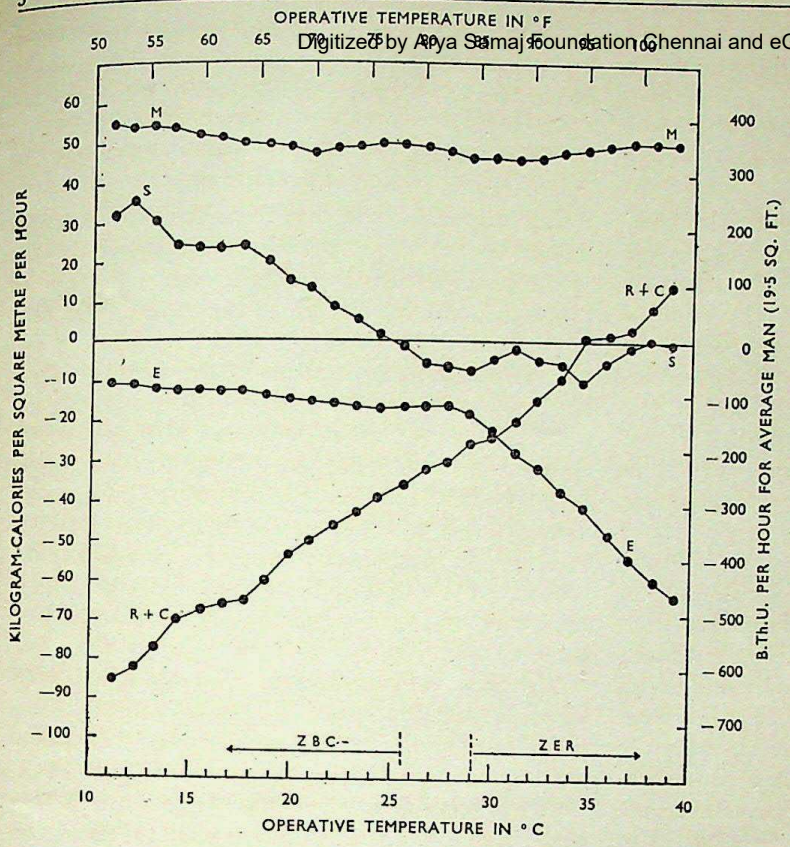

FIGURE 1 – *The relation of the different items in the heat exchange of the clothed body to operative temperature, with air movement of* 0·085 *metre per second* (17 *ft. per minute*) *and medium relative humidity.* M = *metabolic rate;* S = *storage rate;* E = *loss by evaporation;* R + C = *joint loss by radiation and convection;* Z B C = *zone of body cooling;* Z E R = *zone of evaporative regulation.* (*After Winslow*, 1941, Temperature, its Measurement and Control in Science and Industry, 509.)

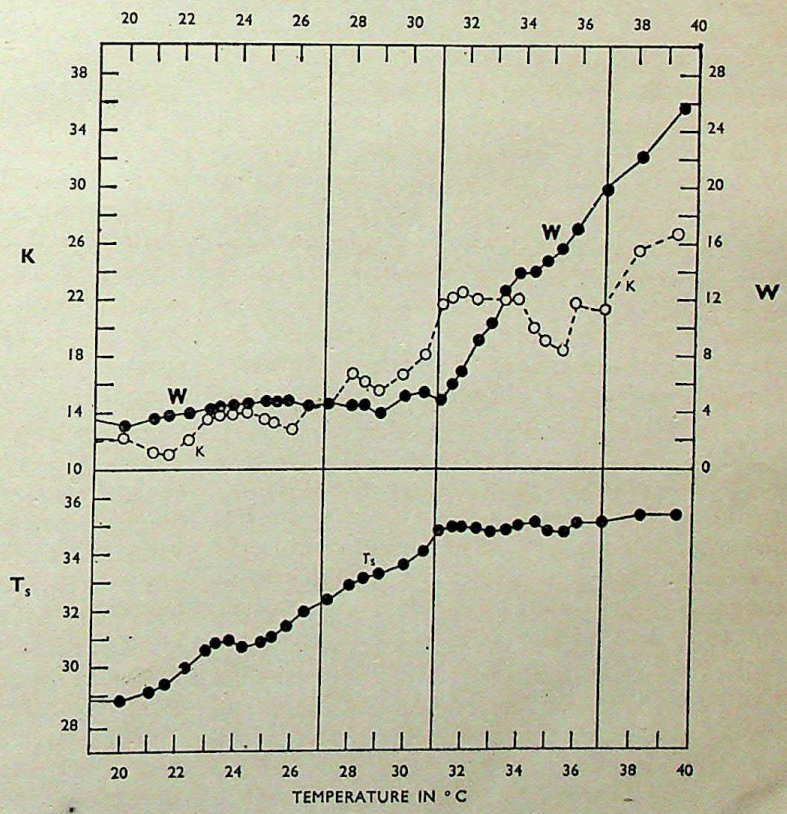

FIGURE 2 – *Physiological response to varying operative temperatures.* W = *wetted area of skin;* K = *conductance;* T_s = *mean temperature of skin* (*for nude subjects*). (*After Winslow*, 1941.)

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the operative temperature rises above 37° C. Experiments indicate that there is a maximum value above which **W** does not increase.

The conductance, K, is a measure of the heat-conducting power of the body. It is equal to the sum of the metabolic and storage rates divided by the difference between internal and skin temperatures. Its value is nearly constant in the zone of body cooling, rises in the zone of vasomotor control, is substantially constant in the zone of evaporative control, and increases slightly in operative temperatures above 37° C. Conductance measures the readiness with which the body-heat is conducted outward to the skin. Experiments show that it is less in fat men than in lean men; and, so far as experimental data are available, less in women than in men. The latter fact is explained by women generally having a more considerable layer of subcutaneous fat than men; in addition, they show a readier tendency to increase their metabolic rate at low temperatures than men. For these reasons, women can bear with equanimity a degree of cold which men would find trying were they protected by only the same amount of clothing. But at higher temperatures the lower conductance of the body in women yields a slower flow of heat outward to the skin, while men sweat at lower temperatures, and sweat more freely at high temperatures, than do women. For these reasons men often find heat less trying than women, though these effects are to some extent counteracted by the greater tendency in women to decrease the metabolic generation of heat at high temperatures. The coloured races in the tropics, who are normally leaner than white men, show less visible sweat, their bodies having in consequence higher conductance than those of white men.

OUT-OF-DOOR CONDITIONS

Out of doors, when the sun is shining, the clothing and skin will absorb short-wave radiation from the sun and the sky, and in sunny weather in hot climates the clothing should be such as to reflect as large a fraction as possible of this radiation.

When the sky is clear there is a net loss of heat by long-wave radiation from the body to the environment, owing to the limited range of wave-lengths in which the atmosphere radiates. This loss is sufficient to be important in the determination of comfort. It is a matter of common experience that on a hot night in summer it is appreciably cooler out of doors than indoors, partly on account of this additional loss of heat and partly on account of the longer retention by inner walls of rooms of the heat gained during the day.

THE EFFECT OF THE VARIATION OF AIR HUMIDITY

The rate of evaporation from the skin is determined by (*a*) the proportion of skin wetted by sweat, and (*b*) the difference between the vapour pressure of air saturated at the mean skin temperature and the vapour pressure in the ambient air. When the temperature of the ambient air is kept constant, and its humidity is increased, the body reacts by increasing the wetted area of the skin, whereby the total loss of heat by evaporation is maintained sensibly unchanged. The purpose of sweating is to maintain the thermal equilibrium of the body, and in any given circumstances the amount of sweating is limited to the lowest value necessary to maintain equilibrium of body temperature.

The skin temperature is scarcely affected by the relative humidity of the air, and only in air of relative humidity above 80 per cent., and temperature above 35° C, is the temperature of the skin appreciably higher than in dry air at the same temperature. At moderate and low temperatures, the loss of heat due to the production of insensible perspiration is independent of atmospheric conditions, and even of whether clothes are worn, being entirely conditioned by internal body factors.

THE EFFECT OF VARYING WIND-SPEED ON EVAPORATIVE LOSS OF HEAT

If we accept the postulate that evaporation of sweat is limited to the lowest value required to maintain body temperature constant, it follows that, in air of any assigned temperature and humidity, the effect of an increase in air-speed will be to increase the loss of heat by convection, and therefore to diminish the loss which must be provided by evaporation. Experimental data bear out this conclusion, showing that the evaporative loss decreases as the air-speed increases and the wetted area of the skin decreases.

The physiological reaction of the body to increasing relative humidity and decreasing air-speed, both of which factors would decrease the rate of evaporation from unit wetted area of the skin, is to increase the wetted area. This is a reaction which cannot be simulated by any instrument, and it is therefore not possible to devise an instrument which will produce a

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response exactly parallel to that of the human body.

THE EFFECTS OF CLOTHING

The interposition of clothing between the skin and the environment checks the interchange of heat by radiation and convection between the body and the air, and provides a protection against either a cold or a hot environment. The loss of heat from the body by radiation and convection is less for the clothed than for the nude subject, but there is little systematic difference between the evaporative loss in the two cases for air temperatures below 35° C. Above this limit the evaporative loss is rather greater for the nude than for the clothed subject. The addition of more clothing will decrease the conduction of heat from the body to the air, just as the addition of another resistance in an electric circuit decreases the current, and the temperature of the trunk of the body can be maintained at a high level by the wearing of sufficient clothing.

THE EFFECTS OF PHYSICAL EFFORT

During physical effort, active sweating sets in at lower temperatures than for the reclining subject. When active sweating occurs, there is a marked fall of skin temperature over the whole body, which facilitates the increased flow of heat from the deeper parts of the body to the skin.

COMFORT IN INDOOR CONDITIONS

A large part of our lives is spent indoors, in conditions in which the evaporative loss of heat from the body is limited to that due to insensible perspiration and the evaporation in the lungs, so that the heat-balance is mainly controlled by radiation and convection. If it may be assumed that the radiating surfaces affecting the body have the same temperature as the air, the clothed body will lose heat by radiation and convection at a rate $(3{\cdot}6 + 10{\cdot}4\sqrt{v})$ units for every degree C difference between the temperatures of the air and of the surface which the body exposes to the air. Here v is the air speed in metres per second. The total rate of loss due to radiation and convection is thus determined by (*a*) the temperature of the ambient air, (*b*) the amount of clothing worn, and (*c*) the air movement. If the rate of loss of heat is too great for comfort, so that we feel cold, we may stir up the fire, put on more clothing, or close the window. When we feel too hot, we may let the fire burn low, shed some clothing, or open the window.

It cannot always be assumed that the effective radiating surfaces in the environment have the same temperature as the air. Inside a steel hut exposed to very bright sunshine the radiation from roof and walls may be so great as to make conditions intolerable. The ideal of painting the outside of such buildings with a highly reflecting enamel paint is not always practicable.

In very hot climates the radiation from the walls of buildings is a very important factor in the maintenance of body equilibrium, and so should be minimized as far as possible by constructing buildings of non-conducting materials of low heat capacity, with double walls and double roofs, separated by a wide air space. A thatched roof has these qualities, and is cool in summer and warm in winter.

In cold weather the walls of a house which has been left unheated during a long spell of cold weather retain their low temperature for some time after heating is started, with resulting discomfort even when the air temperature is reasonably high.

THE LIMITS OF EVAPORATIVE REGULATION; HEAT-STROKE CONDITIONS

When the metabolic rate is known and the skin temperature can be estimated, it is possible to write down an equation expressing the balance between the metabolic rate and the loss or gain of heat by radiation, conduction, and evaporation, in air of any assigned temperature, humidity, and air movement, provided that we may assume the radiating surfaces to be at the air temperature. The equation can be arranged to yield, for any assumed temperature, the maximum relative humidity in which heat balance can be maintained. This process has been followed, assuming air movement 17 ft. per minute, and the results obtained for a reclining subject are shown graphically in figure 3. Here curve AA gives the limits of tolerable conditions for the nude body, and curve BB gives corresponding limits for the clothed body when clothed as described in an early paragraph above. In conditions represented by a point to the right of the appropriate curve, the body temperature will rise, and will continue to rise so long as exposure to these conditions continues. The result will be to lead to heat-stroke. It is seen from figure 3 that, with very high air temperatures, the wearing of clothing is a marked protection against heat. The long loose garments worn by the Arab races afford such a protection against the heat of the air, while also reflecting a large fraction of the incident rays of the sun. In

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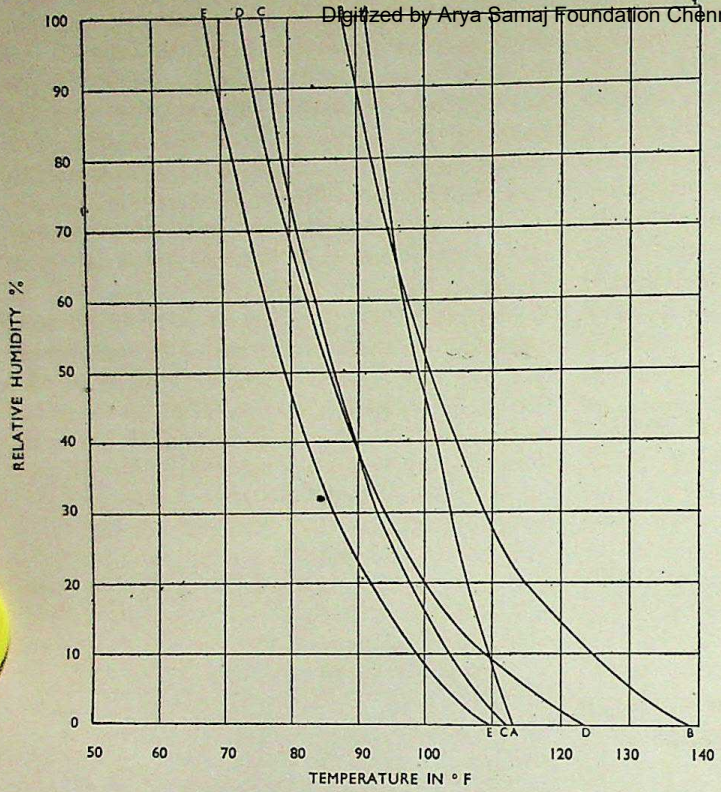

FIGURE 3 – *Curves showing the limits of the range of tolerable conditions for varying degrees of activity;* AA *for nude subjects resting indoors;* BB *for clothed subjects resting indoors;* CC *for clothed subjects resting in sunshine;* DD *for clothed subjects walking at 4 m.p.h. (no sunshine);* EE *for clothed subjects walking at 4 m.p.h. in bright sunshine.*

completely dry air the highest tolerable temperature for the clothed body is 138° F (curiously enough, the highest surface air temperature ever measured was 137·6° F, observed at Azizia, in Tripolitania), while for the nude body the highest tolerable temperature is about 113° F. In saturated air the highest temperature which is tolerable is 88° F for the clothed body and about 92° F for the nude body. This is in close agreewith the findings of J. B. S. Haldane and others, who give 88° F as the limiting temperature tolerable in coal-mines, even by men stripped to the waist and doing no work.

Curves AA and BB of figure 3 are appropriate for men resting, in conditions of light air movement. Any physical effort, by increasing the metabolic rate, will modify the limiting conditions and will shift the curve to the left in figure 3. The presence of sunshine will produce the same effect. Thus, even for a clothed man reclining in bright sunshine, there will be a zone to the left of Curve BB defining conditions in which continued exposure to bright sunshine will lead to heat-stroke.

Curve CC in figure 3 defines the limiting conditions for a lightly clothed man, reclining in bright sunshine, while the limiting conditions for the same man walking at 4 m.p.h., in the shade and in bright sunshine respectively, are given by DD and EE.

The outstanding feature of all the curves in figure 3 is that the drier the air, the higher the temperature which is permanently tolerable.

The statements made above do not preclude the possibility of remaining for brief periods in air at temperatures beyond the limits of permanent tolerability prescribed by the curves AA and BB of figure 3. Blagden described, in the *Philosophical Transactions of the Royal Society of London* in 1775, a stay of eight minutes in a room in which the air temperature varied between 240° F and 260° F. During the first seven minutes of his stay in this room Blagden experienced no discomfort, but after a further minute the rapid increase of distress in breathing and of a feeling of anxiety caused him to leave the room.

THE EFFECT OF INCREASED VENTILATION ON THE HEAT-STROKE LIMITS

When the air movement is increased, both the evaporative and convective losses of heat are increased. In figure 4 are given curves of the limiting conditions for a nude person resting, with six different rates of air movement. An increase of ventilation increases the temperature which can be tolerated with a given degree of humidity, and increases the relative humidity which can be tolerated with a given air temperature. The curves show that three factors are involved in the determination of tolerability of any given conditions. Conditions which are intolerable can be made tolerable by a lowering of air temperature, by a lowering of humidity, or by increased ventilation.

The effect of relative humidity of the air on the limiting conditions is at all times appreciable, and industries which from their nature are damp, as for example laundries, should be sited in places where the air is normally dry.

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The higher degrees of air movement will yield very rapid evaporation of sweat, and the limiting conditions shown in figure 4 are based on the assumption that the body is then wetted by sweat to the maximum extent. A few figures for the rate of evaporation of sweat in the conditions prescribed by the curves are shown in the diagram, where they are expressed in weight of water evaporated in 1 hour by a person of average size. The total loss per hour is considerable, and there is a danger that, in such extreme conditions, the sweat-glands may become exhausted. Should this occur, so that sweating ceases, the body will then be heated by radiation and convection, and its temperature will rise steadily, leading eventually to death by heat-stroke. The deaths due to the simoom, the 'poison wind' of South Arabia, are probably to be explained in this way. Even if the sweat-glands do not become exhausted, but secrete at a limiting rate, there will be a definite wind-speed at which the sweat will evaporate as fast as it is secreted. If the wind rises beyond this limit, the evaporative loss will remain unchanged, while the gain of heat by convection from the air will increase; the result will eventually be death by heat-stroke.

The curves of figure 4 refer to nude persons, subjected to varying conditions of air movement. It is not possible at the moment to draw similar curves for clothed persons. The curve BB of figure 3, which refers to a clothed subject in air movement of 0·085 m. per second (17 ft. per

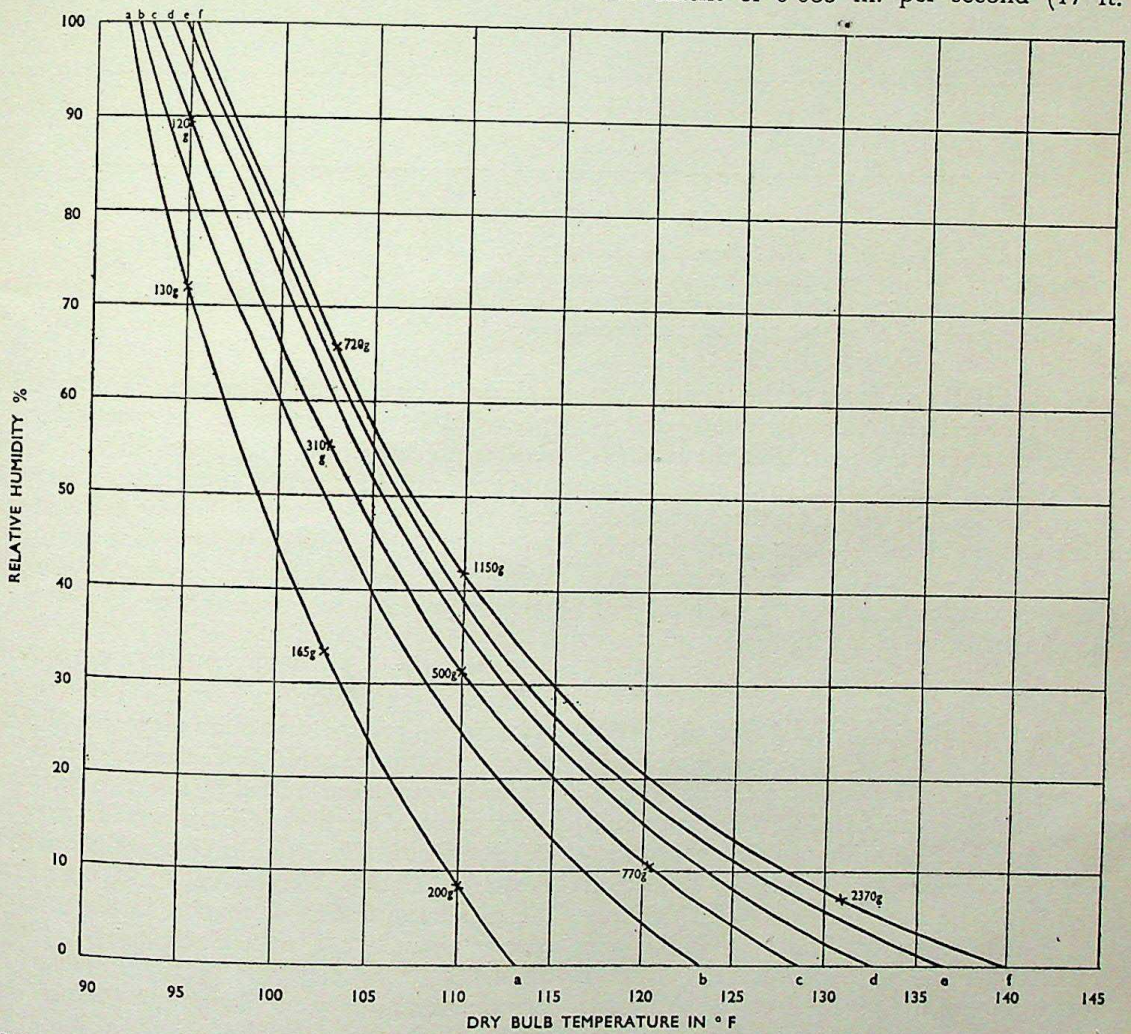

FIGURE 4 – *The effect of ventilation on heat-stroke conditions for nude subjects. The curves give limiting tolerable conditions,* aa *for air movement* 0·085 *metre per second* (17 *ft. per minute*); bb *for* 0·25 *metre per second* (50 *ft. per minute*); cc *for* 0·5 *metre per second* (100 *ft. per minute*); dd *for* 1 *metre per second* (200 *ft. per minute*); ee *for* 2 *metres per second* (400 *ft. per minute*); ff *for* 5 *metres per second* (1,000 *ft. per minute*). *Figures such as* 200g *marked on the curves indicate the rate of loss of water per hour by evaporation from the whole body, skin area being assumed to be* 1·8 *square metres.*

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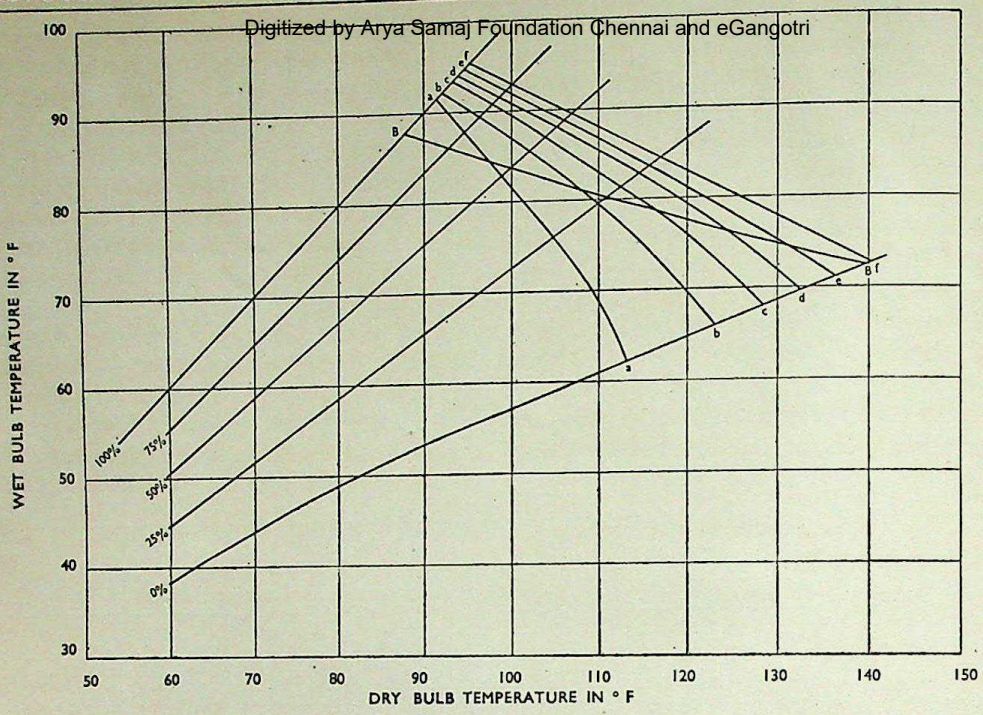

FIGURE 5 – *The limits of tolerable conditions shown in figure* 4 *converted for use with readings of wet- and dry-bulb thermometers. Curve* BB *is the conversion of curve* BB *of figure* 3, *representing the limiting conditions for a lightly clothed person resting. The diagonal lines indicate the conditions in which the relative humidity is* 0, 25, 50, 75, *and* 100 *per cent.*

minute), was based on a value of the conductivity of the clothing which had been derived by experiment with that air movement. But the conductivity of clothing will depend, in a manner not yet known, on the air-speed, since the penetration of the air into the clothing—particularly at neck, sleeves, and legs—depends on this factor. We may, however, take the curves for nude subjects as giving an indication of the effects of ventilation, even on clothed subjects, so far as order of magnitude is concerned.

In figure 5 are shown the same data as are described in figure 4, with air temperature and wet-bulb temperature as the variables, for use in conjunction with observations of wet- and dry-bulb temperatures obtained with a whirling psychrometer. The corresponding curve for a clothed man resting, with air movement of 17 ft. per minute, is added for comparison. It will be seen that, the higher the air temperature, the lower the wet-bulb temperature which can be tolerated.

If we require to determine whether any particular climate will be permanently tolerable, we must consider air temperature, humidity, and wind-speed. The worst conditions are those associated with very light winds, and it is often sufficient to consider air temperature and humidity only. But it is dangerous to assume that it is possible to lay down a definite limit of mean temperature above which man cannot live and prosper. Humidity rather below the half-way limit, or a high average wind-speed at the hottest time of day, may make a somewhat high mean temperature both tolerable and healthy.

COMFORT, HEALTH, AND EFFICIENCY

The limiting conditions prescribed by the diagrams of figures 3, 4, and 5 are those in which the body temperature could be maintained constant, the body being then wetted by sweat to the maximum extent. Such conditions are far removed from comfort. The nude subjects of the experiments by Winslow, Herrington, and Gagge found the maximum feeling of comfort in air temperature of about 29° C, with a skin temperature of about 33° C; for clothed subjects the corresponding temperatures were about 27° C (air) and about 33° C (skin).

We cannot apply these results to the estimation of the conditions of greatest comfort for men leading a normally active life. Comfort is indeed a factor which is difficult to define with clarity.

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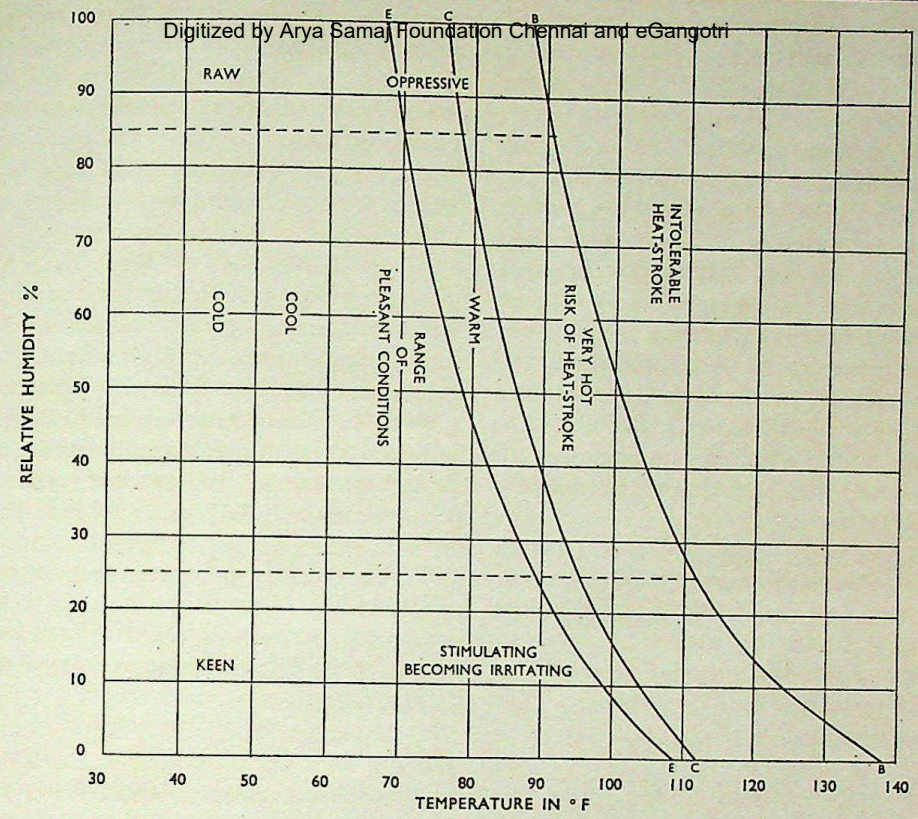

FIGURE 6 – *A tentative classification of climates.*

The slightest physical effort, and even standing up instead of reclining, will raise the metabolic rate, which modifies the heat balance of the body. There appears to be no simple method of carrying the argument further, and we are forced to appeal to purely qualitative observations of comfort or discomfort in different conditions. A tentative summary of such results as appear to be definite is given in figure 6, and this diagram may be taken as a tentative classification of climates. It is based on the assumption of light air movement, 17 ft. per minute, since we have to provide that conditions shall be tolerable when the wind falls off almost to a calm.

In figure 6, the line BB has been copied from figure 3. This line represents the limits of tolerable conditions for a clothed person resting, with air movement of 17 ft. per minute. To the right of this line are conditions of temperature and humidity such that continued exposure leads to rise of body temperature, followed by heat-stroke. The region to the right of line BB in figure 6 is therefore marked 'heat-stroke.' To the left of this line there is a region in which conditions will be classed as 'very hot,' even by a person resting, while a relatively slight physical effort will cause the body temperature and the pulse-rate to rise. The line CC of figure 3 has been inserted as the lower limit of the 'very hot' region, on the assumption that 'very hot' applies to conditions in which it is impossible to walk at 2 m.p.h., or to rest in bright sunshine, without rise of body temperature.

A region to the left of CC is marked 'warm,' and this region is bounded on the side of low temperatures by the line EE, which represents approximately the limiting conditions in which a man can walk at 4 m.p.h. in bright sunshine without rise of body temperature. This boundary is tentative, and is possibly too far into high temperatures for very low humidities.

The lowest temperatures which are tolerable or comfortable are not readily fixed. It is generally agreed that below 50° F it is 'cold,' and that below 60° F it is 'cool,' except for a man making a considerable physical effort. The cold region, below 50° F, may be further subdivided. Damp air, of relative humidity above 85 per cent., then yields the conditions known as 'raw,' the discomfort of which is due to condensation of water vapour in the clothing, leading to an increase in conductivity of the clothing, and consequently to increased convective loss of heat. At

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the other end of the humidity scale dry air of relative humidity 25 per cent. or less, gives that stinging feeling of cold to which we give the name 'keen.'

Saturated or nearly saturated air is at all temperatures unpleasant. Even at a temperature of about 70° F, it is distinctly oppressive, and at very high temperatures the feeling of oppression becomes still more marked. Again, while short exposure to very dry air is found to be rather stimulating, long-continued exposure is irritating, leading to headaches, depression, lack of energy, and a strong tendency to become quarrelsome. This action of very dry air is particularly noticeable where the Föhn wind is common, but is observable in many parts of the world, notably among dwellers in desert regions.

Within the limits of desirable climates tentatively fixed by figure 6 between the 60° line and EE, there yet remains a wide choice of temperature and relative humidity, and with medium relative humidity there is a range of temperature extending from about 60° F to 75° or 80° F within which a man may feel a reasonable degree of comfort.

Experience of air conditioning in many countries has shown that it may be accepted that with relative humidities of 40 to 70 per cent. men doing light work indoors can do so with maximum comfort in air temperatures above 60° F and below 76° F. The optimum actually prescribed will vary in different countries, according to the clothing worn, the degree of physical activity, the average conditions out of doors, and the type of heating and ventilation used. It is agreed that very high and very low degrees of relative humidity are to be avoided—high values because they lead to a feeling of oppression and low values because they eventually produce restlessness and irritability. The differences in what are regarded as the optimum conditions in different countries may be illustrated by a comparison of the recommendations for indoor air conditioning made in England and in the United States. With medium relative humidity the summer optimum is 66° F in England and 76° F in the United States; and the winter optimum is 62° to 64° F in England and 72° F in the United States.

In such climates as those of most countries in the middle latitudes of both hemispheres, some degree of air conditioning is necessary in order to produce indoor conditions compatible with comfort and efficiency. In England and other parts of the British Isles the heating of homes is still very largely by open coal fires, and should the same method continue to be used in the future, cheap coal will remain a necessity if the health and efficiency of the nation are to be maintained. If the coal fire should be replaced by some other form of heating, that form of heating must be cheap.

SEEKING THE IDEAL CLIMATE

In any attempt to determine the ideal climate it is necessary to bear in mind the variation of temperature at any one place during the twenty-four hours of the day. This variation may amount to over 40° F in certain localities. The lowest temperatures occur at about sunrise, and most of the period of low temperatures comes at a time when the bulk of the population is in bed. Under the bedclothes the air temperature is usually 85° to 86° F. We may therefore discount some of the effects of the diurnal variation of temperature, since exposure to low night temperatures is restricted to a relatively short period for the average citizen.

If we accept the limits of figure 6 as fixing the limits of desirable climate to a reasonable degree of certainty, we may conclude that, with average relative humidities, the temperature to which a man is exposed when he is not making great physical effort should lie between 60° F and about 75° F. We may therefore define the ideal climate as one in which the air temperature rarely exceeds 75° F, and rarely falls so low that it becomes difficult to raise the indoor temperature to that value between 60° and 75° F which is regarded as desirable. When air temperature falls below the freezing-point even by day, it becomes costly and troublesome to maintain an indoor temperature of over 60° F.

It is estimated that in bright sunshine and with air temperature 67° F a lightly clothed man could walk at a rate of nearly 4 m.p.h. without sweating, and could either sit in the sun or stand in the shade doing light work without body cooling. This would appear to fix an ideal for an active outdoor life for a lightly clothed man. With little or no clothing, a somewhat higher temperature would be desirable, so that the ideal would probably exceed 70° F.

At this stage it is of some interest to look at a world map of the mean temperatures of the year. On such a map, the isotherm of annual mean temperature 70° F passes through Memphis, Palestine, and the centres of the early civilizations of Assyria, Sumeria, Persia, and not far north of

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the site of the early Indian civilization at Mohenjodaro in the valley of the Indus. The early civilizations of Africa and Asia thus arose in regions where the mean temperature of the year was very close to 70° F. The summer would have been hotter than this, and summer afternoons probably so hot that the siesta must have been a biological necessity rather than a luxury. The winter would have been too cold for comfort without some special protection. In none of these ancient civilizations was the heating of buildings customary, and it was only when the control of indoor temperatures became common, in the days of Greece, and still more in the Roman Empire, that an advanced civilization developed at an appreciably lower annual mean temperature than 70° F. After the fall of the Roman Empire, the custom of controlling indoor conditions slowly died away, and the next civilization, the Muslim, was in the region of the 70° isotherm. It was only with the rediscovery of brick-making, the invention of the fireplace and chimney as we know them, and the use of glass for windows, all in the thirteenth century, that any degree of winter comfort became possible in most European countries. By the middle of the sixteenth century, the middle and upper classes in England had draughtproof houses, with glass windows instead of slits in the walls, and with coal-burning fireplaces and chimneys. The general use of coal spread to the villages soon after this period. It may not be without significance that the glories of the Tudor era in England came so soon after the use of coal for heating had become common. England's very plentiful supplies of coal gave her a great advantage over many of her competitors in the race for superiority which she eventually won.

According to F. S. Markham's book, *Climate and the Energy of Nations*, when a white man migrates to a country where the hottest month of the year has a mean temperature exceeding 75° F, he finds that, whereas he and his children may be able to cope with the altered climatic conditions, his grandchildren will show a marked loss of energy and of efficiency, both physical and mental. It is doubtful whether this rule holds in all its simplicity for all countries. Some allowance must be made for atmospheric humidity, as well as for the effect of wind-speed, on the tolerability of otherwise hot conditions. Major Markham has, however, marshalled a considerable mass of material, relating to health and economic conditions, which appear to bear out his views as to the general range of climatic conditions which are permanently tolerable by white men, and to suggest that the 'poor white' problem is partly climatic. There is, however, a wide range of problems of settlement of white races still remaining to be investigated, and as the problems of the settlement of white peoples in hot climates promises to become important at the close of the present war, it would appear highly desirable that there should be a world inquiry into these problems, which are not entirely limited to economic and medical factors, but include also an important climatic factor that cannot be neglected.

The ideal climate would seem to be one in which the mean temperature of the hottest month of the year does not exceed 70° F, or at most 75° F, while the mean temperature of the coldest month does not fall below 40° F, or at lowest below 32° F. New Zealand offers what is in many ways the most attractive approach to this ideal, as over most of the country the mean temperature of the hottest month lies between 62° and 70° F, while that of the coldest month lies between 45° and 52° F. The healthy nature of the climate is borne out by the fact that, during the ten years 1926–35, New Zealand had a death-rate and an infantile mortality-rate of 8·4 and 40 respectively, both the lowest recorded values for any country in the world. The corresponding rates for the United Kingdom were 12·2 and 67 respectively.

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Types of man-made fibres

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W. T. ASTBURY

'You will never make a Sattin purse of a Sowes ear,' said the old proverb. This precise metamorphosis is still impossible, but chemists have closely approached it: for from the fats and proteins of a sow's ear it is possible to synthesize nylon, one of the most successful of man-made fibres. Dr Astbury, who with his colleagues has made the chief advances in the protein fibre field, has a fascinating story to tell of man's rivalry with Nature.

Biological fibres are of the nature of molecular yarns spun from long chain-molecules. It may seem almost obvious to us now that this should be so, but in fact it is a generalization that has emerged clearly only within the last twenty years. And it is one of the great generalizations of our time, not simply as regards its industrial implications, gratifying though they are, but in a much wider and more wonderful sense. In the make-up of living tissues chain-molecules are pre-eminent, and the study of their forms and combinations is fast laying the foundations of a new biology. It is not directly with such high adventures, however, that we are concerned here, but rather with some of the lessons that have been learnt from them. The purpose of this article is to explain how man has set about making fibres in Nature's image, and to classify the results of his efforts in terms of chemical constitution and physical properties.

In what follows we shall be wise after the event and talk as though there was always a conscious striving after suitable kinds of chain-molecules and methods of spinning them. That, of course, is not so. There must long have been the desire to imitate spiders and silkworms by some process of extruding and coagulating viscous solutions—witness, for example, Hooke's whimsical suggestion, in his *Micrographia* (1664), of 'a pretty Kinde of artificial Stuffe' that might be drawn into fibres—but until comparatively recently that seems to have been as far as it went. Success came empirically in the latter half of the nineteenth century with the discovery how to dissolve and resolidify cellulose and some of its derivatives; and though it was recognized that the molecules of cellulose must be very large and that the high viscosity and 'spinnability' of its solutions were bound up with this fact, it remains that people were wearing 'artificial silk' before their benefactors properly understood what they were doing. The story would sustain a nice argument between those who contend that scientific progress reflects the demands of the age and those who hold rather that scientific advances actually inaugurate new eras. It is impossible to dissociate fibre science from a strong industrial urge, but likewise it is undeniable that researches into more and more complex molecules, particularly those of biological origin, were in any case reaching an exciting stage. The important point is that the two lines of approach have now run together into what in the end amounts to a single subject, the study of chain-molecules—and whether they are in hair or nylon, eggs or plastics, cabbages or kings, matters little.

In the biological world, as just said, fibrous structures, or what are effectively fibrous structures when we penetrate to the molecules themselves, are of the very nature of things; and similar types of chains are used over and over again in all sorts of guises and groupings. Since, then, such chains, in the long trial of evolution, have been found worthy of so heavy a responsibility, the obvious first course in attempts to make fibres of our own would be to make further use of the self-same molecules, either by collecting them from natural sources or by synthesizing them. On the long view the latter procedure is the more satisfactory, but for the present our chemistry is not equal to the task, and we can do no more than refashion or remould existing raw material. This is the basis of the 'regenerated' fibre industry—the science of isolating, controlling, and if necessary modifying, natural chain-molecules and building them into structures of our own design. In the meantime, however, pending the day when we shall have succeeded in synthesizing some of the more difficult components of ourselves and other living creatures, there is no reason why we should not try to evolve other chain-molecules—simpler ones, of course—and make play with those, thereby at the same time generating new effects, over and above those already met with in

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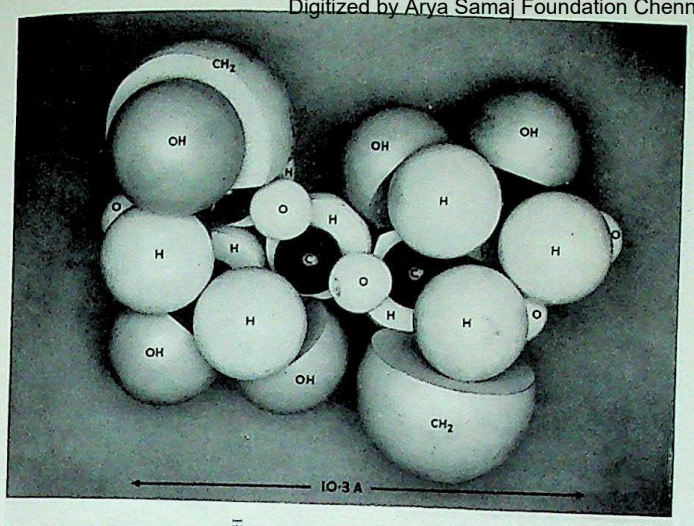


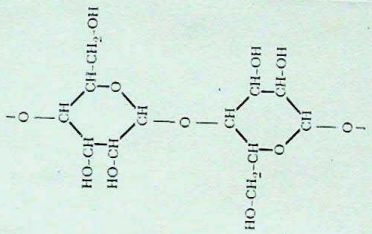


FIGURE 1 – *Scale model of two consecutive links in the cellulose chain.*

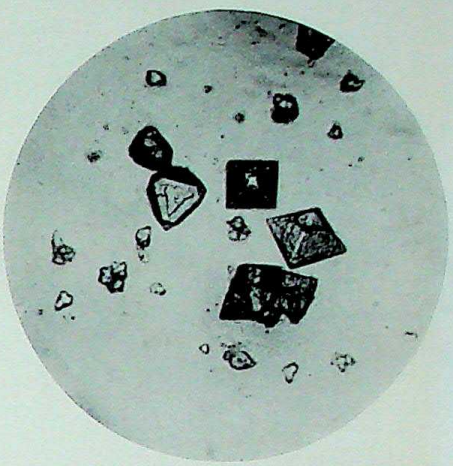
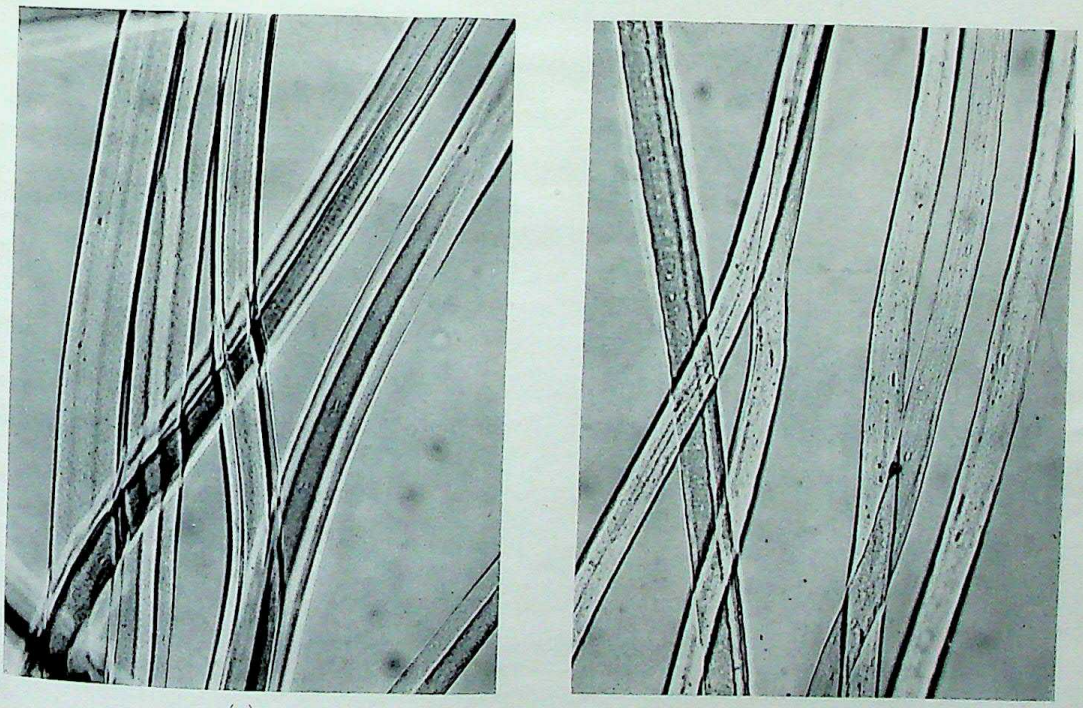


FIGURE 2 – *Microscopic crystals of edestin, the globulin from hemp-seed.*



(*a*) (*b*)

FIGURE 3 – *Regenerated protein fibres:* (*a*) *from the arachin of pea-nuts;* (*b*) *from the casein of milk.* (× 250.)
(*Photomicrographs by J. Manby, University of Leeds.*)

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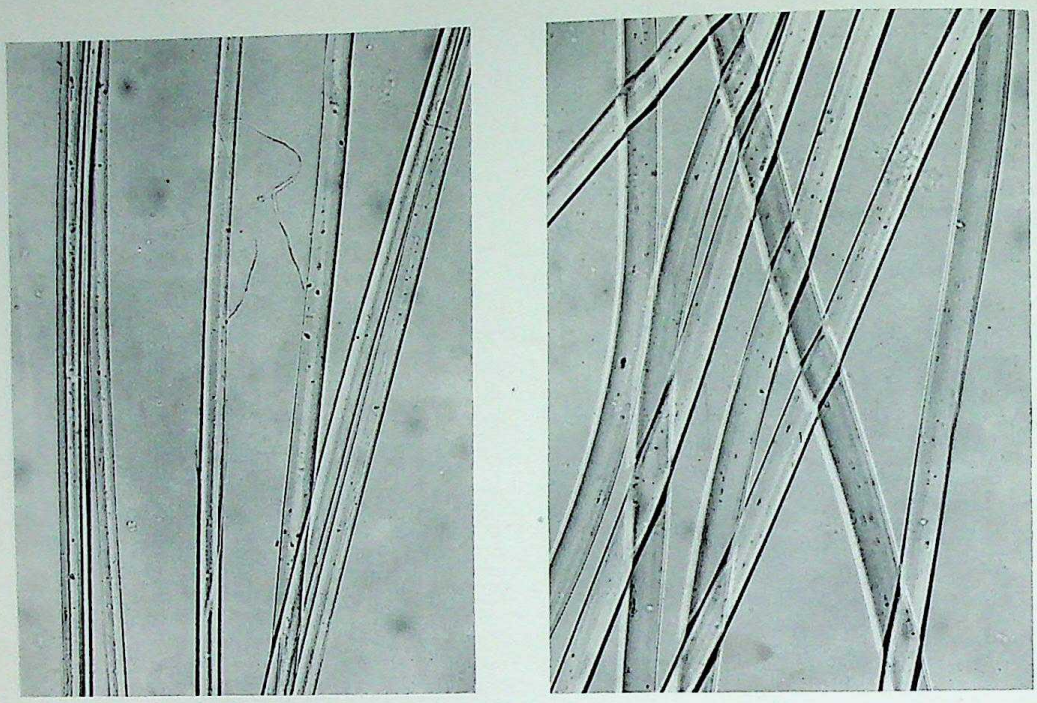
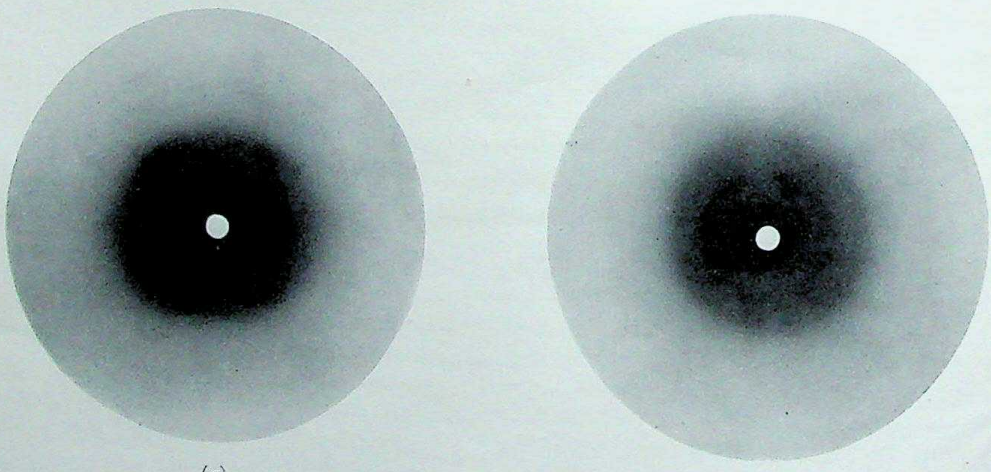


(*a*) (*b*)

FIGURE 4 – *Synthetic fibres:* (*a*) '*vinyon*'; (*b*) *nylon.* (× 250.)
(*Photomicrographs by J. Manby, University of Leeds.*)



(*a*) (*b*)

FIGURE 5 – *X-ray photographs of 'vinyon': (a) stretched; (b) contracted in steam to about one-fifth of its stretched length. (Fibre axis vertical; CuKa-rays; D ≈ 3 cm.)*

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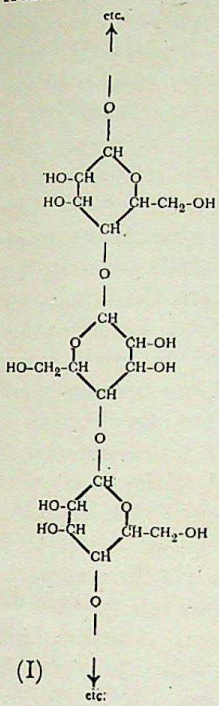
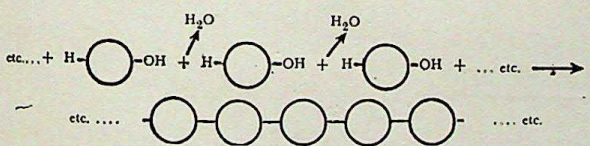
Nature. This is the basis of the synthetic fibre industry—the science of making fibres 'from scratch'[1].

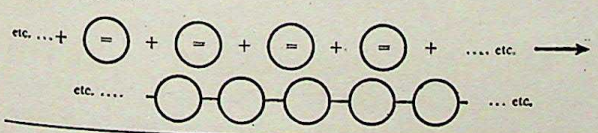
The two classes of regenerated fibres start one from polysaccharides and the other from proteins. The polysaccharide-in-chief is cellulose, the main framework substance of the vegetable kingdom and the most abundant organic compound in nature. The cellulose molecule (I) is a chain of hundreds or thousands of β-glucose 'residues.' It is worth while delaying for a moment to make clear the meaning of the word 'residue,' since it is sometimes loosely stated that the cellulose molecule consists of a chain of β-glucoses, or that the proteins consist of chains of α-amino acids. The two methods of building chain-molecules are by repeated condensation or by polymerization, the former process involving at each linkage the elimination of (generally) the elements of water, and the latter the opening of a double bond followed by direct addition. With sufficient generality for our purpose the two schemes may be represented symbolically as follows:



Polycondensation



Polymerization



The linked units in either case are called residues, and the chain is usually spoken of as a high polymer, whether it was formed by polymerization or not. Cellulose $(C_6H_{10}O_5)_n$ is formed from β-glucose, $C_6H_{12}O_6$, by the process of condensation. Formula (I) is a convenient quick way of writing down the atomic arrangement, but it is no more than that, because chains of residues of other sugars may be written similarly. It requires perspective drawings or models to show the spatial relations of the hydroxyl groups and the configuration of the molecule as a whole—and, it should be emphasized, such things are indispensable in the scientific study of fibre structure. Figure 1 will convey some idea of the actual shape of the unit that runs through the cellulose story. The chains themselves are very long and somewhat stiff, and in the more crystalline regions of the fibres they are stereochemically fully extended and are held together strongly by means of hydrogen bridges between hydroxyl groups[1].

There is no question of melting cellulose and redrawing it from the molten state as may be done with many synthetic high polymers: natural structures, such as wood, have to be broken down, purified from non-cellulosic constituents, and dissolved in special solvents such as our old laboratory friend, Schweitzer's reagent (cuprammonium). In the manufacture of viscose, the commonest type of rayon, the cellulose is brought into solution by a combination of caustic soda and carbon disulphide and regenerated by squirting through the fine holes of a 'spinneret' into an acid bath. The regenerated cellulose molecule appears to be essentially the same as in the native state, except that it is likely to be shortened by hydrolysis at some of the bridges between the glucose residues. X-rays show, however, that the state of side-to-side aggregation is different: the product is what is known as hydrate, or mercerized, cellulose, being crystallographically the same as that into which native cellulose is transformed in the well-known process of mercerization, which does not involve solution proper, but a mere swelling with alkali and water.

The properties of artificial filaments depend on the chemical constitution of the chain-molecules, and on the length, orientation, and regularity of the chain-bundles or 'micelles.' Strength, for

[1]It is perhaps unfortunate that there is as yet no agreed nomenclature for man-made fibres. The need for such agreement is likely to become more pressing as chemistry makes increasing advances into the realm of textiles. The words 'rayons,' 'prolons,' and 'synthons' have been proposed for fibres of cellulosic, protein, and synthetic origin respectively; but these are not generally acceptable. A proposal to use the word 'rayon' to cover all non-natural fibres is even less acceptable, while the word 'artificial' is felt in the textile trade to be derogatory. For the purposes of this article we accordingly fall back on the broad classification into 'regenerated' and 'synthetic.'

[1]We may perhaps dispense with reproducing any X-ray photographs of cellulose or its derivatives because they are now fairly familiar. The reader will find a selection of X-ray fibre photographs in an article by the writer in the April 1942 number of ENDEAVOUR.

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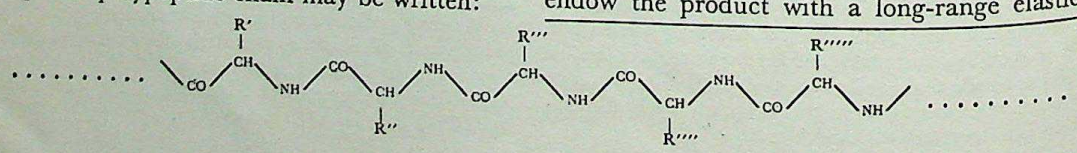
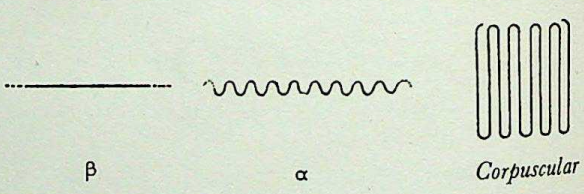
instance, is a function of the degree of crystallinity and parallelism to the fibre axis. X-ray analysis provides the best all-round help in keeping track of fibre properties in terms of internal arrangement, and the subject owes a great deal to it; but to feel happy in the field requires much more, a co-ordination of techniques and data that may be no more than hinted at in an article of this kind. The cellulose story alone is immense—filaments of cellulose and its derivatives are still overwhelmingly the commonest of man-made fibres—but briefly we may say that it falls into three parts. The first has to do with 'straight' regenerated cellulose (products such as viscose, cuprammonium rayon, and so on), while the second is concerned with chemically modified cellulose, derivatives such as ethers and esters, the most notable example of which is acetate rayon. Substitutions in the hydroxyl groups of the glucose residues can of course give rise to a great range of molecular affinity, both between the chain-molecules themselves, leading to a variety of mechanical properties, and between the chains and accessory reagents—dyes, for example. It should be added that the uses of regenerated cellulose and its derivatives are not confined to fibre production: there is a considerable industry devoted to the manufacture of films, sheets, and other shapes.

The third part of the cellulose story is by way of being an intercalation on processes for imparting properties that are more the prerogative of the protein fibres. 'Tebilizing,' for instance, makes cellulose fabrics crease-resisting through an intimate incorporation in the fibre substance of the cross-linked chains of urea-formaldehyde resin, while so-called 'animalized' rayons show certain protein dyeing properties by virtue of the presence of other synthetic polymers. This brings us now to the field of the regenerated protein fibres, in which the technological development finds much of its inspiration in a desire to imitate the natural protein fibre, wool, more closely still. The underlying scientific ideas derive mostly from the X-ray interpretation of protein structure, and particularly from the X-ray discovery of the general relationship between the fibrous and the crystalline, or 'corpuscular,' proteins.

The proteins are organized systems of polypeptide chains, alone or in combination with prosthetic groups. A polypeptide chain may be written:



where R′, R″, etc. stand for about two dozen different kinds of side chains that theoretically may be distributed in an enormous number of ways. That is to say, whereas cellulose is a polycondensation product of β-glucose only and (except for end-groups) consists therefore of residues of a single kind, the proteins are polycondensation products of α-amino acids of widely different chemical functions whose residues have only the formula (–CO–CHR–NH–) in common. As a result, the conventional polypeptide chain just set out hardly begins to portray the stereochemical possibilities. Even in the protein *fibres* the fully extended configuration already given is comparatively rare. It is found in natural silk (fibroin), for example, but in mammalian hairs the chains are normally in a regularly folded configuration (α-keratin), from which they are pulled out straight (β-keratin) when the fibres are stretched, and to which they return when the tension is removed. This intramolecular transformation is the basis of the long-range elasticity of a great family of fibrous proteins that includes, as shown by X-rays, not only the keratinous fibres such as wool and so on, but also those of the epidermis, the elastic protein of muscle (myosin), and the blood-clotting protein, fibrinogen. All these have a similar shape of molecule that lies intermediate between the fully stretched form of silk and the highly folded forms of corpuscular proteins such as egg-albumin, haemoglobin, edestin, etc. The transition from one extreme to the other may be represented diagrammatically as follows:



When the intramolecular folds specific to a protein are irreversibly disarranged, the protein is said to be 'denatured,' and the science of making regenerated protein fibres consists in unfolding suitable corpuscular molecules by the action of denaturing agents and drawing out the liberated polypeptide chains into less folded, elongated configurations. Sufficient vestigial folds remain to endow the product with a long-range elasticity

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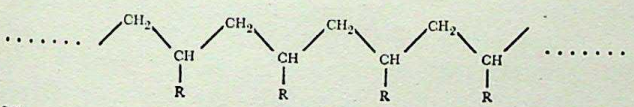
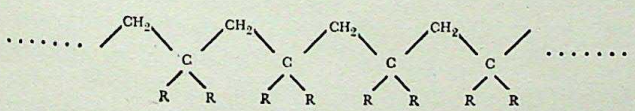
roughly analogous to that of wool. The denaturing agent may be an alkali or strong urea solution, and the viscous solution so produced is then spun into coagulating and hardening baths. The milk protein, casein, was one of the first to be converted into fibres in this sort of way—along empirical lines, however—but following the X-ray elucidation of the process it is now known that many other corpuscular proteins offer themselves, particularly the seed globulins found in pea-nuts, soya beans, and the like. Figures 2 and 3 (*a*) and (*b*) will bring home the dramatic nature of the change from crystalline protein to soft, elastic fibres—incidentally, as striking a demonstration of the unity of the physical, chemical, and biological sciences on the one hand, and of science and industry on the other, as may well be imagined.

The regenerated protein fibre industry is still in its infancy, and so is the synthetic, to which we now turn to complete this skeleton-like sketch of a tremendous body of knowledge and craftsmanship. Synthetic fibres are resins or plastics often spun from the molten state, and their production is an affair of modern chemistry and chemical engineering[1]. The two general methods of building up linear high polymers have been indicated above, and all we shall add to that is to say that both schemes are in use, and already with such success that, under appropriate physico-chemical conditions and with the aid of catalysts, it is now possible to synthesize chains many thousands of residues long. Favourite monomers are vinyl and vinylidene derivatives, polymerizing to chains of the type:

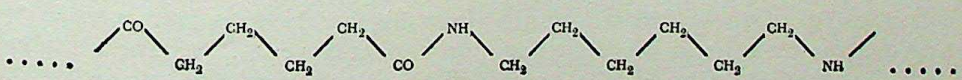


or



Not all such chains are fibre-forming in the best technological sense, however, because their physical properties in the mass depend on their length, the nature of the R-groups, and the temperature. Broadly speaking, good fibres are formed by long chains with not too much sideways asymmetry, though that is not the whole story by any means. Temperature is a very important factor—linear high polymers belong to the class known as 'thermoplastics,' and a product that is hard and brittle at low temperatures generally becomes plastic or rubbery at higher temperatures. What seems to have been the first commercial synthetic fibre is 'vinyon' (figure 4 (*a*)), a co-polymer of vinyl chloride, $CH_2{=}CHCl$, and vinyl acetate, $CH_3{\cdot}COOCH{=}CH_2$. An X-ray photograph of a specimen of 'vinyon' that had been submitted to an extra stretching in the laboratory is shown in figure 5 (*a*), while figure 5 (*b*) is a photograph of the same specimen after exposure to steam. It is included to illustrate the property of thermo-elasticity, so characteristic of many linear high polymers. Above about 70° C (in the case of 'vinyon') thermal vibrations disarrange the chain-molecules that at ordinary temperatures remain 'frozen' roughly parallel to the fibre axis (*see* figure 5 (*a*)): they coil up and the fibre rapidly contracts to only a fraction of its initial length. Figure 5 (*b*) shows the almost amorphous nature of the contracted state.

The most successful synthetic fibre to date is nylon. This is a class-name that has been given to polyamides formed by the repeated condensation of dicarboxylic acids and diamines, generally of the type $COOH{-}(CH_2)_x{-}COOH$ and $NH_2{-}(CH_2)_y{-}NH_2$. The acid and base commonly employed are adipic acid and hexamethylene diamine respectively, leading to chains of the formula below. Nylon has an exceptionally low affinity for water, and it can be drawn into thicker filaments for toothbrushes and surgical sutures, for example, or into the finest fibres with the strength and resilience of natural silk. So outstanding are its properties that nylon is monopolized for the time being almost entirely for war purposes.



[1] See, for example, the article on polythene by J. C. Swallow in the January 1944 number of ENDEAVOUR.

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Movements of the tongue in speech

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J. YULE BOGUE and DENNIS FRY

To understand the mechanism of speech, a close study of the movements of the tongue is essential. This presents obvious difficulties under normal conditions, but recently a unique opportunity arose of cine-photographing tongue movements during speech. A simultaneous sound-record was made, and some of the most important conclusions are described in this article, which is illustrated with remarkable photographs taken from the film.

Though many languages are spoken and many different pronunciations, even in one language, are recognized, the mechanism by which speech is produced is the same in all cases. The organs involved are the lungs, which serve as an air reservoir, the larynx, the soft palate, the tongue, and the lips, all of which modify the outward passage of the air-stream in such a manner as to produce speech. It is, however, the tongue which is largely responsible for those sound differences which characterize a particular pronunciation. For this reason a study of the tongue in movement is essential for a proper understanding of the mechanism of speech.

Until recently, our knowledge of these movements has been gained very largely by subjective investigation—that is, by a subjective correlation of muscle movements with the auditory impressions of the sounds produced by them. One consequence of this has been a tendency to connect the different speech-sounds with a series of static positions of the tongue rather than to consider the effect of its movement.

The co-operation of a patient whose tongue was exposed to view as the result of an operation involving the removal of his right cheek enabled us to record on film both the sounds and the tongue movements.

The words and sentences recorded were chosen so that the film might cover the widest possible range of sounds. We have, in fact, records of all English sounds except a few which occur but rarely, and certain labial ones which were deliberately omitted because the subject's lip movements were abnormal. The film presents the material in three sections: first, a group of isolated words demonstrating the movements which accompany the production of various vowels; second, a series of words all containing the same vowel preceded and followed by different consonants; and third, some short sentences showing the action of the tongue in current speech.

The subject, 72 years of age, was born in London and has lived there all his life. Certain of the sounds he uses are characteristic of the London regional accent. His speech habits have not yet been very much affected by adaptation to his new condition.

In the work which we are describing here, all possible means were adopted to increase the value of the records obtained. The chief source of information is a 'Technicolor' film record of the tongue movements taken at the normal rate of 24 frames per second. A simultaneous sound recording of the subject's speech was made, so that it is possible to compare the pictures with the sounds corresponding to the tongue movements. Further, the film sound-track, which is of the variable area type, supplies a rough indication of the wave-form of the sound which is being produced. In addition to these records made at normal speed, high-speed photographs were taken at a rate of 1,000 frames per second. These shots can be projected at the normal rate, so that the tongue movements are slowed down approximately 40 times; they are, however, intended mainly for frame-by-frame analysis in conjunction with cathode ray oscillograms of the speech-sounds taken at the same time. This analysis in itself will constitute a long research project, and it is impossible, at present, to state what new light may be thrown upon the subject. The results will be particularly valuable because the high speed at which the record was obtained ensures that every movement of the tongue may be followed to its limits.

The normal-speed film has already revealed facts of general interest; it is possible to give here only one or two examples. The traditional method of classifying vowels by tongue 'position' refers different vowel qualities to the part of the tongue concerned in their articulation. The film record shows very strikingly that the general shape which the tongue adopts, and the movement of the whole

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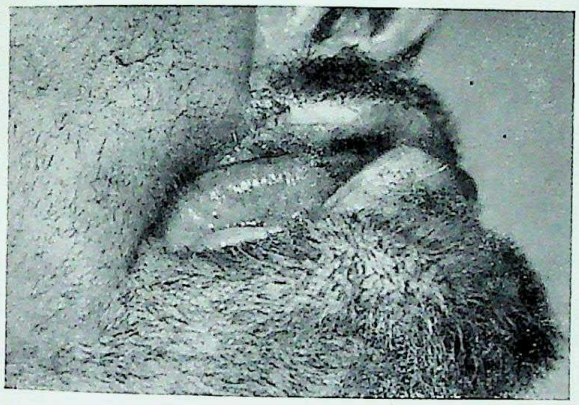
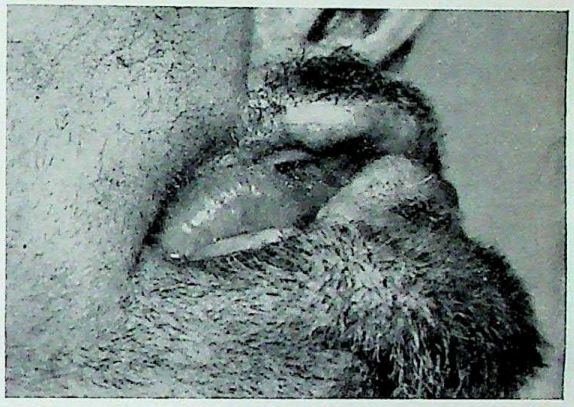
FIGURE 1 – *The forward contact for* l *in* lad.

FIGURE 2 – *The tongue-tip rolls back for* r *in* rag.





FIGURES 3 and 4 – *In both* s *and* sh *the tongue shows a characteristic furrowing, but moves further forward in* s *than for* sh.

tongue with relation to the mouth cavity, are the governing factors in determining vowel quality. So, for example, in the vowel series of *he, him, hem, ham,* where the traditional theory would expect a progressive lowering of the front of the tongue, the film shows that the modification of vowel quality is achieved by bunching the tongue together rather than by any considerable lowering.

Perhaps the most striking of the demonstrations supplied by the film concerns the welding of a succession of sounds into a continuous chain. As soon as we see the tongue really in movement it is evident that all movements during one sound-group must be interdependent. The idea of a series of 'tongue positions' giving rise to a series of sounds appears quite artificial, and the theory of assimilation (that is, the influence of one sound upon another) loses much of its meaning. The film shows that often a very small movement of part of the tongue is sufficient to produce in one context the acoustic impression of a particular sound which in another context may require a full-scale movement of the whole tongue. A good example of this is provided in the film record of the sentence *There's a crowd in the back room,* where the vowel of *in* entails only the slightest movement of the tongue-tip, whereas the 'same vowel' in *him* shows a considerable movement of the whole tongue.

The business of learning to speak, which most of us perform quite naturally by imitation, does in some cases require external aids. The deaf-mute, for example, has to be taught to speak through a long and laborious process of learning to make the correct muscle movements deliberately, and in some cases of nervous disease it may be necessary to carry out complete speech re-education. Even less complicated tasks, such as learning to pronounce a foreign language, entail the learning of new muscular habits. The primary aid to this process is the ear, and where the hearing is normal we may be sure that it will do

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सन्दर्भ ग्रन्थ
REFRENCE BOOK

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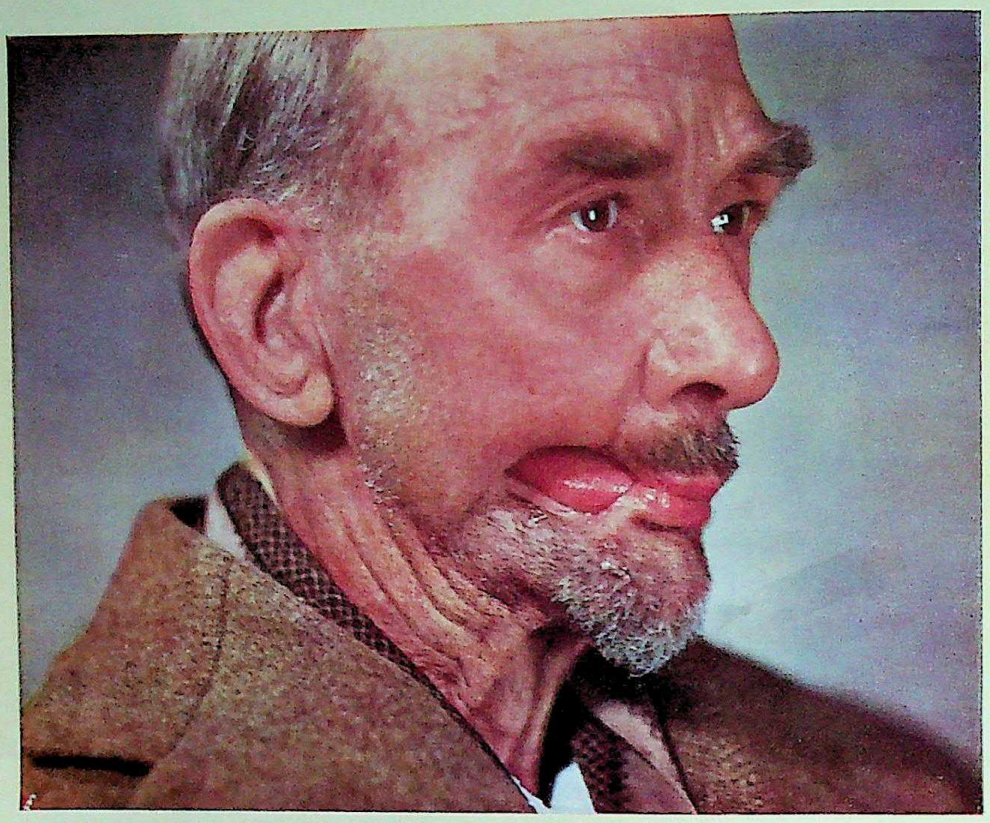

FIGURE 5 – *The tongue in a typical rest position.*

the major part of the work. Even so, it is often necessary to assist the ear with various visual aids. When the hearing is defective, acquisition of the muscular habits of speech depends on the visual and kinaesthetic senses, and we have to seek ways of presenting the speech processes to the eye.

The sound film of tongue movements has suggested a new technique for this purpose. We have now at our disposal a moving picture of the tongue as it produces the sounds used in pronouncing English. Any part of this film record can be selected and made into a loop, so that when it is projected the same series of movements and sounds is presented to the student over and over again. This method has the great advantage that sound sequences can be broken down into their component parts, or into isolated sounds when necessary, and these can be built up again into longer and more complex groups as the student progresses. A series of loops of all the sounds, syllables, words, and sentences which are demonstrated in the film will in due course be available for instructional purposes.

Deaf-mutes quite often have a very small amount of residual hearing which it is important to utilize when teaching them to speak. Since the film has a synchronized sound-track, we have a convenient means of presenting an auditory stimulus perfectly synchronized with the visual one. It is only necessary to take the signal from the sound track, to amplify it and feed it into a pair of headphones, and we have a hearing aid for each patient. Any hearing he may have is thus utilized.

Note. The colour plates, figures 6, 7, 8 and 9, demonstrating the action of the tongue for certain sounds during speech, were selected from a series of photographs made by means of a gas discharge lamp giving an exposure time of a fraction of a millisecond. Figures 1, 2, 3, 4 and 5 are enlargements taken from the normal-speed 'Technicolor' film, each exposure being of the order of 0·02 second.

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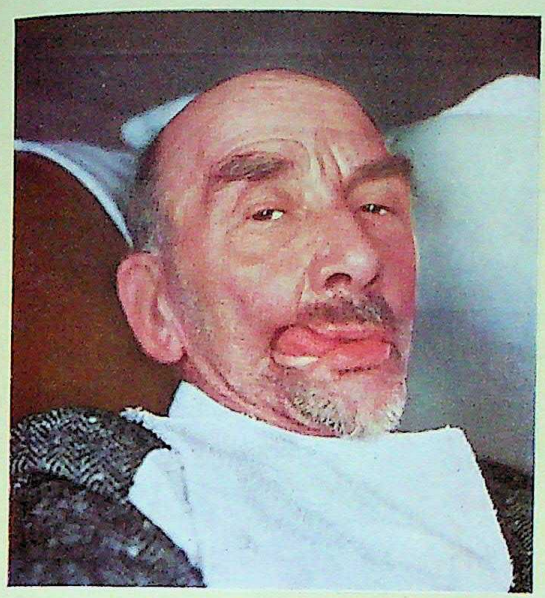

FIGURE 6 – *View showing the tongue arched towards the front of the mouth for the vowel in* he.

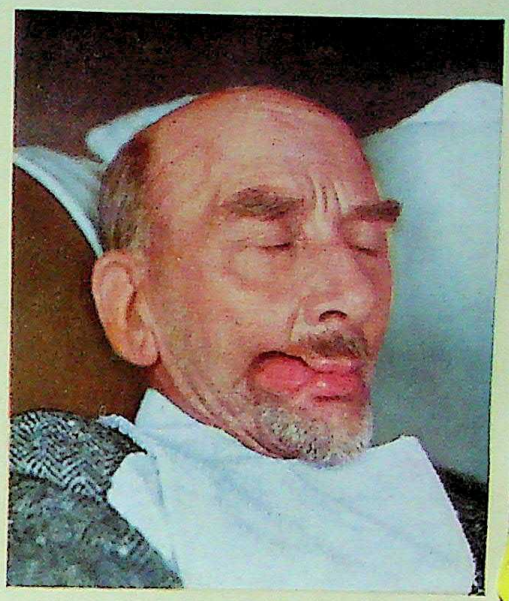

FIGURE 7 – *The tongue lowered and retracted for the vowel in* harm.

FIGURE 8 – *The tongue-tip makes a forward contact for* t *in* part-time.

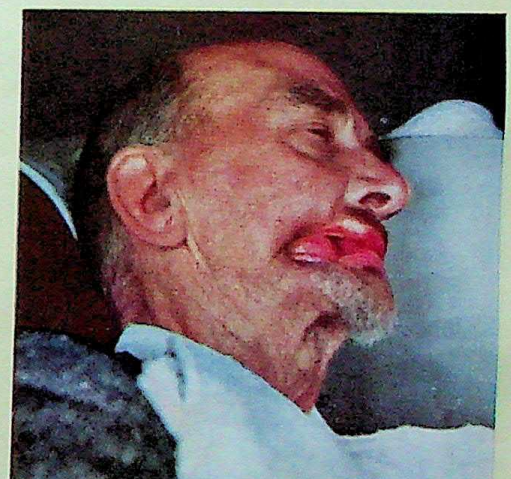

FIGURE 9 – *In the* k *of* black-case *the tongue is arched and retracted to make contact with the soft palate.*

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Giant nerve-fibres

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J. Z. YOUNG

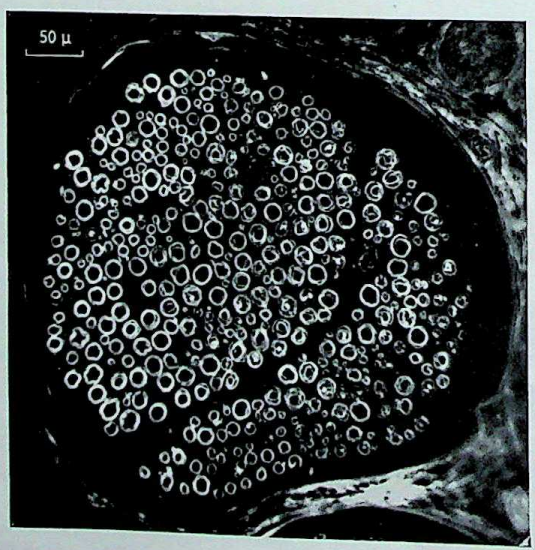
Certain transparent tubular structures in the squid were at first supposed to be blood-vessels. Mr. Young discovered that they are in fact giant nerve-fibres, and the discovery has led to important advances in our knowledge of the nature of nerve-substance and its activities. Of particular significance and value is the light it has shed upon the regeneration of nerves after injury, a subject of especial interest in times of war.

The nerves in the arms or legs of a man are shining white strands containing thousands of nerve-fibres, each one of which is only a few microns[1] in diameter (figure 1). Their function is to conduct sensory messages from the skin to the brain and motor messages back from the latter to the muscles. Each nerve-fibre conducts messages concerned with a single function only; thus there are separate fibres concerned with each of the various types of sensitivity in the skin (touch, warmth, cold, pain) and other fibres responsible for producing contraction of the muscles. Where any delicate functions, involving detailed sensory discrimination or fine movements, are concerned, very numerous nerve-fibres are necessary. For this reason the nerves in the limbs of man are much larger and contain more nerve-fibres than those of other animals.

In all the nerves of man and other vertebrates the number of fibres is rather large and their diameter small. This has been something of a handicap in investigation of the nature of nervous conduction. However, in some of the invertebrate animals there are nerve-fibres of much larger diameter. In 1933, while investigating the nervous system of the squid, I noticed certain transparent tubular structures of about a millimetre in diameter. At first I took them to be blood-vessels and paid little attention to them, but the peculiarities of their microscopic appearance gradually persuaded me that they were nerve-fibres, of a diameter several times greater than that of any others known. It was obvious that if this were so they would provide magnificent opportunities for experimental work, but first it was necessary to study their structure, connections, and functions and to show that they really were nerve-fibres.

The squid is a very common marine animal, related to the octopus. It is caught in large numbers by fishermen in many parts of the world, but a considerable difficulty in working with squids is that they are very active and need a large volume of water. It is therefore impossible to keep them alive away from the sea and even hard to bring them ashore alive, since they are easily damaged in a trawl. However, thanks to the co-operation of Dr Stanley Kemp and his staff at the Laboratory of the Marine Biological Association at Plymouth, supplies of live squid were made available. It was possible to prove that these structures are in fact enormous nerve-fibres, and that they are very suitable for experimental purposes. During the years before the war numerous investigators made use of them, at Plymouth and at the marine station at Woods Hole, Mass., and it was found possible to investigate several properties which could not be studied with smaller fibres.

FIGURE 1 – *Photograph of cross-section of a portion of a mammalian nerve, showing fibres of all diameters from 20 μ downwards. (Photograph kindly supplied by Dr F. K. Sanders.)*



[1] 1 micron (1 μ) = $\frac{1}{1000}$ mm., or $\frac{1}{25000}$ in.

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These large nerve-fibres are used by the squid for its peculiar method of propulsion, which is on the rocket principle (figure 2). A jet of water is squirted from a sac-like organ, the mantle, through a tube which can be directed forwards, backwards, or sideways. The squid uses this mechanism for sudden quick darts through the water, while for more delicate movements it possesses a pair of fins.

The jet is produced by circular muscles whose contraction makes the whole sac smaller. These muscles contain tens of thousands of separate muscle-fibres, but they are worked by only ten nerve-fibres, which are large and graded in size, the hindmost and longest being also the largest. Investigation of one of these nerves confirms that the single large nerve-fibre controls all the muscle-fibres in the hind part of the sac. After the large fibre has been pricked, or otherwise damaged, electrical stimulation no longer produces the quick contractions of the muscle [13]. This demonstrates decisively that the structures in question are nerve-fibres. To produce an effective jet the sac must contract as a whole, and this is ensured by having few and large nerve-fibres, leaving little provision for the performance of graded contractions. The movements of the fins, on the other hand, being delicate, require many nerve-fibres. As figure 3 shows, the nerves here contain numerous small fibres, besides the single very large ones.

Like all nerve-fibres, these giant ones show electrical changes during their activity. It has long been known that as a nerve-message travels the active region becomes electrically negative to all neighbouring regions. Two electrodes placed on a nerve and connected with a suitable amplifying and recording device will therefore register a diphasic change as the impulse passes each electrode in turn (figure 6). It is obviously of great advantage to be able to study these changes in a single nerve-fibre, but with the small fibres of vertebrates this can be accomplished only by the use of a very special technique. In the squid it can be done much more satisfactorily, and without any elaborate preparation, by simply removing the nerve from the animal, laying it on electrodes connected with an amplifier, and applying some stimulus at one end. The potential developed by the activity of the large fibre is so much greater, and is conducted so much faster, than that of the others that it stands out conspicuously (figure 6). Figure 7 shows the record of a series of such impulses which Dr H. K. Hartline and I recorded at Woods Hole. In this case the nerve was activated by applying a solution of sodium citrate to one end; this precipitates the calcium and initiates a rhythmical discharge. In normal functioning, only one such impulse passes over the giant nerve-fibre for each single contraction of the mantle sac.

Many investigators have taken advantage of the ease with which the electrical activities of these squid nerve-fibres can be recorded for further investigation of the propagated impulse. The nature of nervous conduction has of course been studied for many years, and we already have perhaps more information about it than about any other bodily function. The great simplification produced by working with readily accessible large fibres has not only allowed direct confirmation of previous deductions but has made possible the investigation of many new aspects of the process.

It has long been supposed that an essential feature of nerve is that there is a potential difference, the resting potential, between the inside and the outside. This has been confirmed directly by investigations such as that of Hodgkin and Huxley [7], in which an electrode was inserted inside the giant nerve-fibre. The potential difference arises from the fact that the nerve surface is composed of a differentially permeable membrane which, together with the chemical changes going on inside the cell, leads to an unequal distribution of charged particles. In particular, it has been suspected that potassium is present in much greater quantities inside than outside nerve-fibres. This has now been proved by direct analysis of the uncontaminated squid fibres. The actual difference is considerably greater than had been estimated, making various assumptions, from analysis of whole nerve trunks. Webb and I at Plymouth [12] found a concentration of potassium inside the fibres twenty-nine times as great as that outside, and Bear and Schmitt [1] at Woods Hole found a figure of twenty-six times. Sodium and chlorine, on the other hand, are present in smaller amounts within the fibres than around them. If we assume that the membrane is almost impermeable to anions and to the larger cations such as Na^+, but fully permeable to K^+, then the magnitude of the potential should be given by

$$\mathcal{E} = \frac{RT}{F} \log_e \frac{[K^+] \text{ inside}}{[K^+] \text{ outside}}$$

This was calculated for each of the fibres which we analysed and compared with the actual

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potentials which had been recorded from the fibres before analysis. The observed potentials were on the average 7·5 mv. below the calculated ones, a discrepancy of about 10 per cent. Considering the difficulties involved, this provides a strong indication that the potential is a potassium diffusion potential. However, this cannot be more than a part of the whole story, if indeed it is correct at all. Steinbach and Spiegelman [11] have recently shown that sodium can enter and potassium leave the fibres quite readily, so that evidently the diffusion potential hypothesis will not cover all the facts.

During the passage of the nerve-impulse the membrane becomes freely permeable to all ions and a current flows between the active and neighbouring regions, causing breakdown of the membrane of the latter, so that a wave of discharge sweeps over the fibre. Dr Cowan of University College, London, showed some time ago that during this process potassium leaks out of the nerve-fibres. Evidently the characteristics of the membrane at rest and in activity are of fundamental importance, and K. S. Cole and his colleagues have now been able to measure the membrane characteristics directly, by inserting electrodes inside the nerve-fibres [3]. They find that the electrical properties of the membrane are equivalent to those of a circuit containing a capacity shunted by an inductance and a rectifier in series. This effect is to be expected in a membrane with selective permeability separating two electrolytes; and Cole suggests a quasi-crystalline, piezoelectric structure for the membrane, as an explanation of the inductance. Hill [6] has shown that the heat evolved during passage of an impulse is smaller than the free surface energy of an oil-water interface, such as is probably involved. We still know too little to be certain of the actual changes which occur, but Danielli [4] has produced a theory based on the assumption that the increase of permeabilities is due to an alteration in the closeness of packing of the molecules, which would result in an evolution of heat of the order of magnitude of that which Hill observed.

One of the most remarkable characteristics of modern biology is the way in which various techniques contribute to understanding of living activities. The old distinction between structure and function breaks down, and we find that information obtained with various optical and other physical and chemical techniques all converges to give us an idea of the living processes. This has been conspicuously true in the case of nerve-fibres. Besides the electrical studies mentioned above, there have been optical investigations of the fibre in ordinary and polarized light, showing the presence of a longitudinal organization in the molecules of which the nerve-fibre is composed [2]. By squeezing out the contents from the end of a dissected giant fibre, about 10 mg. of pure 'axoplasm' can be obtained; and with such material, besides the analyses of potassium described above, investigations of the nerve-proteins have been made. Recently Richards and his colleagues [10] have studied further details of the fine structure with the electron microscope, finding rodlets of all sizes from 15 mμ upwards.

This information about the nature of nerve and its conduction enables us to understand much more about the factors which determine the velocity of the nerve-impulse. In a system such as has been described the conduction velocity should be increased (*a*) by increasing diameter, giving lowered internal resistance; and (*b*) by changing the characteristics of the membrane. The latter method is that which has been adopted in vertebrates, where each nerve-fibre is surrounded by concentric layers of orientated fatty molecules making the 'myelin sheath.' In the squid no such thick layer is present, but since there are nerve-fibres of diameters varying between 1 μ and 1 mm. this animal is ideal for investigation of the effect of diameter. Actually it is not easy to use quite the full range of fibre diameters, but Pumphrey and I [9] found that rates of conduction varied between 3 and 22 metres per second with diameters from 40 to 718 μ. The rate appears to follow approximately the square root of the diameter, a result which agrees with some theoretical expectations.

From these results it is also possible to see the value to the squid of a series of nerve-fibres of graded diameter. If all the fibres conducted at the same rate, the front end of the sac-like mantle would close before the hind. Actually the conduction-rates in the nerve are so adjusted that contraction of the whole sac occurs nearly simultaneously. The presence of giant fibres also significantly lessens the time taken by the animal in getting under way. Rapid conduction is very necessary for an active life, especially in a long animal. The conduction-rate in the largest nerve-fibres of the squid is about 25 metres per second, whereas in the smaller, numerous fibres, such as those innervating the fins, it is not more than 5. Probably it takes the animal not longer than 50 msec. to get under way after some attractive

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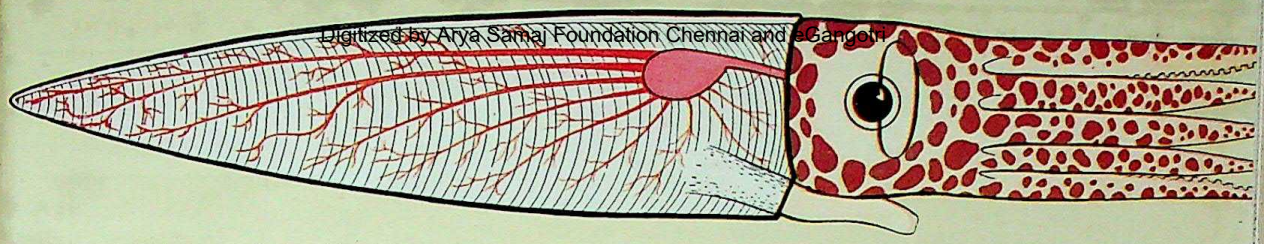

FIGURE 2 – *Diagram of a squid with the mantle-sac cut open to show the stellate ganglion (pink), from which emerge ten ner each containing a giant fibre (red). The fibres increase in size posteriorly, and as the conduction-rate increases with the diame the nerve impulses reach all parts of the mantle-sac at about the same time.*

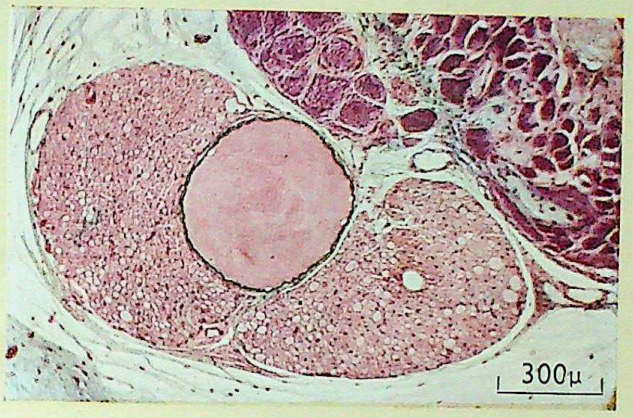

FIGURE 3 – *Photograph of transverse section of one of the stellar nerves of the squid as it is leaving the ganglion. One very large fibre is seen, surrounded by a sheath of collagen stained green. The remainder of the nerve is made up of numerous small fibres. Above the nerve is seen a portion of the ganglion, the Nissl substance, characteristic of nerve-cells, being stained purple. Section stained with Masson's trichrome method.*

FIGURE 4 – *Longitudinal section of a nerve which had been cut five days previously and the ends then brought together. The central end lies to the left and contains nerve-fibres from which new processes (f) are growing out into the damaged region. Here they meet special columns of cells (c) which grow out from the peripheral stump to meet them. This and the next figure are of preparations stained with Bodian's silver stain for nerve-fibres and Masson's trichrome stain. The nerve-fibres are black or purple-brown, blood-vessels orange, connective tissue green.*

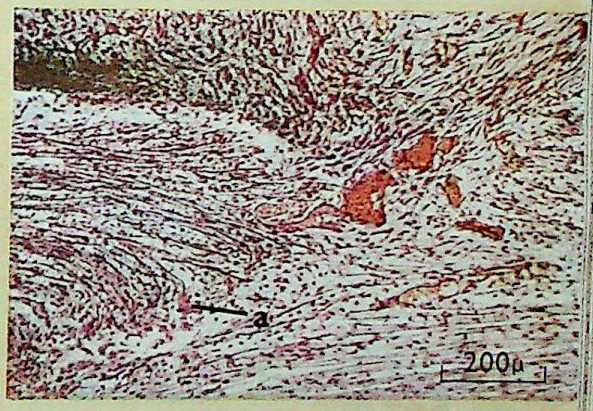

FIGURE 5 – *Longitudinal section of a rabbit's nerve whic had been cut five days previously and the ends not proper joined. The central end lies to the left. New material (a is growing out from its nerve-fibres, but is blocked and unab to connect with the peripheral stump.*

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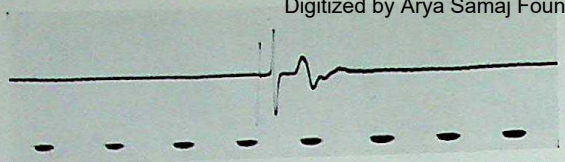

FIGURE 6 – *Record of action potential in nerve of a squid. The nerve has been laid across electrodes, two for stimulation and two connected with an amplifier. The record reads from left to right. The first oscillation is produced by the application of the stimulus, the second by the giant fibre, and the subsequent ones by the combined effect of the smaller fibres in the nerve. The time-signal marks indicate* 10 *msec.*

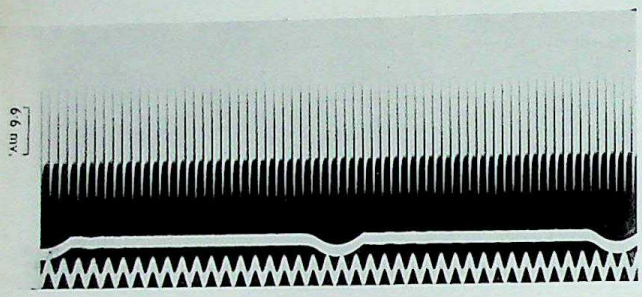

FIGURE 7 – *Record of repetitive discharge in giant fibre of a squid to one end of which a* 1 *per cent. solution of sodium citrate has been applied. The time-markers show* 10 *and* 200 *msec.*

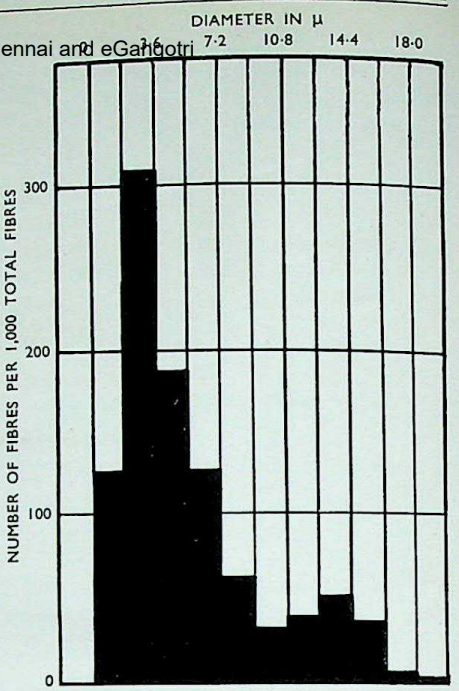

FIGURE 8 – *Histogram to show the numbers of fibres of different sizes in a motor nerve of a rabbit. (Figure kindly supplied by Dr F. K. Sanders.)*

or unattractive picture has fallen on its retina. Of this time only about 15 msec. is occupied by conduction along the nerve-fibres, so that if these were small, and conducted at, say, 5 metres per second, the animal would take at least twice as long to start.

The giant squids such as *Architeuthis*, which live in the depths of the sea, are much larger than the common forms (*Loligo*) which we have been considering. A specimen which had been washed up at Scarborough, and which I examined in the Natural History Museum at South Kensington, had a mantle 125 cm. long, and its total length, including the tentacles, must have been over 2 metres. Much larger specimens have been recorded. But the nerves of the above specimen contained no fibres larger than 250 μ. There is no reason to think that these conduct any faster than would fibres of the same size in *Loligo*. Moreover, the nerves in the long arms do not contain giant fibres. Therefore it must take at least a second for a message to go from end to end and back in these animals. This confirms certain other evidence that they are rather sluggish creatures, though no doubt very formidable, with their suckered tentacles and beak-like jaws.

Other very elengated animals also make a considerable saving of time by having large nerve-fibres. When an earthworm is touched it withdraws surprisingly rapidly, and the message is conducted by fibres which are about 100 μ in diameter and also have a fatty sheath. Some years ago we were able to show that these conduct at about 25 metres per second, that is to say at a speed reached in the squid, which has no thick fatty layer, only by much larger fibres. Similarly crustaceans, such as the crayfish, have large nerve-fibres to conduct messages to initiate the quick flip of the tail by which they escape.

The constant high temperature which is maintained by birds and mammals increases the speed of conduction to more than 100 metres per second, which means that a message can go from end to end even of the largest whale in a fraction of a second. We can see the advantage of such rapid conduction when we consider that in ourselves, if there were no conduction faster than 1 metre per second, it would take more than a second for the leg to be withdrawn after contact of the foot with a hot surface or pin.

A very interesting point is that the nerve-fibres in any one animal do not all conduct equally fast. In mammals each sensory or motor function is subserved by fibres of a particular diameter. Each nerve thus contains a spectrum of fibres of different diameters and conduction-rates (figure 8).

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The fastest ones, with a diameter of about 20 μ (including a sheath of 5 μ), are those which carry impulses from the central nervous system to the muscles. Speed is probably important here not only because of the time saved but also because it ensures that the contraction of numbers of muscle-fibres shall be nearly simultaneous. The messages concerned with touch are carried at about 25 metres per second. Curiously enough, the fibres dealing with pain are many of them very small and conduct only at about 1 metre per second. Lewis [8] has shown that there are also other pain fibres conducting at a faster rate, and that when the skin is pricked with a pin we can distinguish between the fast pain which comes first, and the later pain arriving in the slower fibres.

This question of the spectrum of fibres present in a nerve brings us to an aspect of work on nerves which is of especial interest in war-time, namely their regeneration after injury. When a nerve has been severed, the nerve-fibres disappear from that portion which has been separated from the central nervous system, leaving in this peripheral stump only the framework of the nerve composed of connective tissues and other elements. The nerve-fibres of the central stump, however, remain intact and soon begin to put out new growths (figures 4 and 5). If the divided ends of the nerve-trunk have been stitched together, these outgrowths from the central fibres grow down into the peripheral stump and ultimately reach the muscles or skin. But we have seen that a large nerve contains thousands of different nerve-fibres, and that these include several groups having different diameters, conduction rates and functional connexions. If proper regeneration of function is to take place, appropriate new connexions must be made. Motor nerve-fibres must join up with muscles and not with skin and so on. It has often been suggested that special forces of attraction are at work ensuring the correct connexions. But recent work in this department and elsewhere has shown that the connexions of the two stumps are made at random. Each of the (say) ten thousand fibres in the central stump divides and puts out numerous branches, and these grow down whichever tube in the peripheral stump they happen to contact. Many wrong and some right connexions will be made in this way, and it is possible that there is some mechanism by which the incorrectly connected fibres are later removed.

Study of the diameter of the newly formed fibres in the peripheral stump shows that it approaches only very slowly towards normal. Even in so small an animal as the rabbit the process is not complete one year after a nerve has been sutured, and the spectrum of fibre sizes probably never again becomes normal [5]. It is no wonder that after severance of a nerve the return of function is never completely satisfactory. Muscle movements remain poorly co-ordinated and there may be abnormal pains and other sensations. The more we know of nerve conduction and regeneration the more likely we are to be able to prevent or correct these disabilities. The very fact that the body provides even a very slow mechanism for regeneration after injury shows the fundamental importance of the nerves. It is satisfactory that we know something about them, but all this is only a beginning, and we may hope that some day it will be possible to give a much more complete account of the forces at work in nervous conduction and regeneration.

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Artificial cooling and its vital services

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JAMES SMALL

As applied to the preservation of food, and its successful transportation over great distances, mechanical refrigeration has effected a great and lasting economic revolution. Professor Small sketches in non-technical language the development of this aspect of artificial cooling, which in time of war is of literally vital importance and which in the years of peace to come will bring men easement and health. Much of the fundamental work was British.

The process of cooling, if it is a planned and deliberate action, is artificial no matter how simple the means may be by which the aim is achieved. For 'artificial cooling' we may substitute the term 'refrigeration,' which, properly applied, means the process of cooling to any temperature below our common experience, whether it be below the freezing-point or not.

THE EARLY ARTS OF COOLING

The early civilizations were all located in countries in which the warmth of the sun was often a burden. The ancients had therefore a greater appreciation of coolness than we in Britain have much reason to acquire, and we may well believe that they were willing to go to a great deal of trouble even to enjoy the refreshment of a cooling drink—as indeed they were. In the winter season snow was collected where it could be found, compressed to a solid block of ice, and carried, sometimes over long distances, in simply insulated containers to be stored in cellars for use in the hot season. There is evidence that this practice existed among the early Chinese, the Jews, the Greeks, and the Romans.

A cool drink was usually obtained by melting a piece of ice in the beverage itself. But there were no rules of hygiene observed in the collection or the storage of the ice, and the Romans became aware that a great deal of illness arose from indulgence in cooled drinks. To avoid this they resorted to the cooling of beverages from outside the container. In other words they introduced the idea of the ice-pail or the champagne-cooler. This innovation is, surprisingly enough, attributed to the Emperor Nero, who as a student of natural phenomena is usually accredited with an interest in combustion rather than refrigeration.

THE BEGINNINGS OF THE SCIENCE OF COOLING

The marked degree of cooling which follows the blowing of air upon a surface which has been wetted by a liquid more volatile than water is a matter of long-standing experience, and was for many years used by physicians as a means of obtaining local anaesthesia.

The basic work in this field was done in the College of Glasgow about two hundred years ago by the great physician William Cullen, who was its first lecturer in chemistry. He demonstrated that the boiling-points of liquids vary with pressure, and that cooling may be effected by promoting evaporation through a reduction of pressure. In an essay written in 1755 Cullen says:

> In an experiment made with nitrous aether, when the heat of the air was about 43°, we set the vessel containing the aether in another, a little larger, containing water. Upon exhausting the receiver [in which the vessels were placed] and the vessels remaining for a few minutes *in vacuo*, we found the most part of the water frozen and the vessel containing the aether surrounded with a thick and firm crust of ice.

So far as is known this is the first record of the production of ice by artificial means. It was Cullen's pupil and successor, Joseph Black, who formulated the theory of latent heat. In doing so he made a major contribution to the science of refrigeration.

DEVELOPMENT OF MECHANICAL REFRIGERATORS

No attempt to embody Cullen's experiment in a commercial machine was made until about the year 1834, when Jacob Perkins built a compression refrigerator to use a volatile liquid as a working substance. Had he persisted in his original intention of using 'sulphuric ether' he might well have had the first successful ice-making machine to his credit, for his apparatus had all the essential features of the practical vapour-compression machines of the present day.

The first continuously acting machine was perhaps one invented by Dr Gorrie of New Orleans

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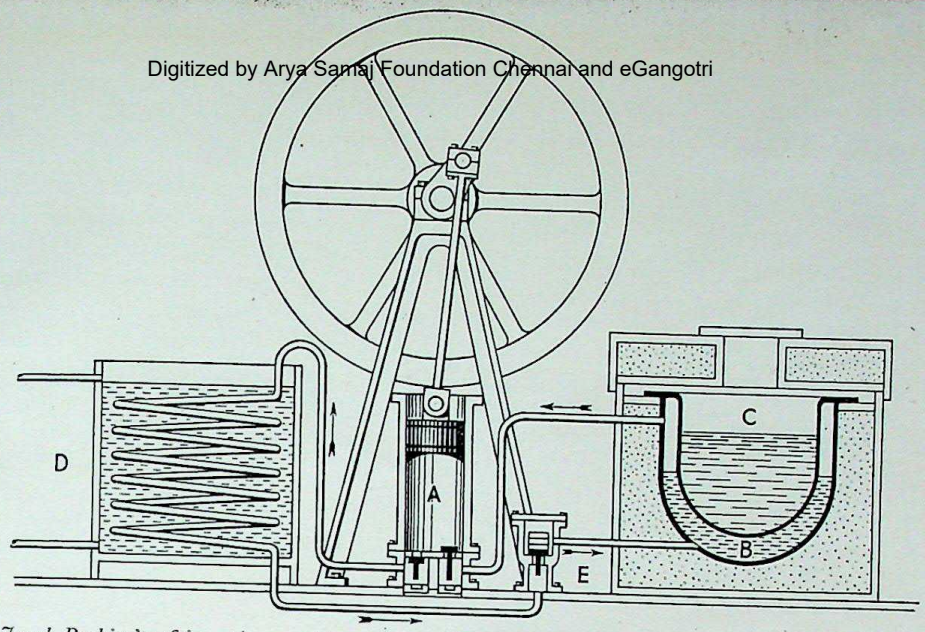
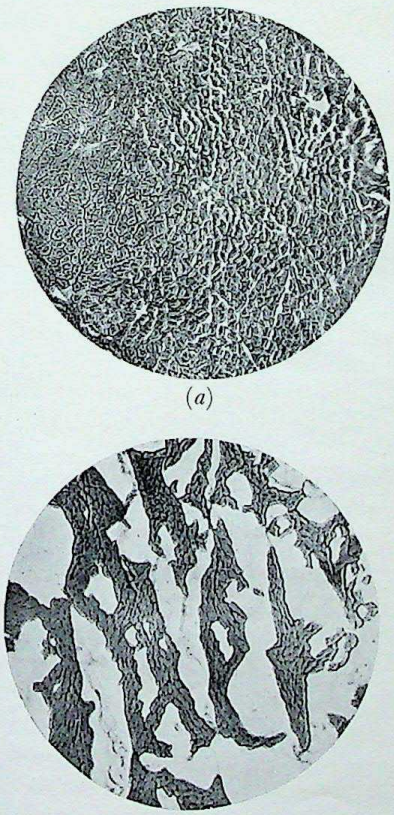


FIGURE 1 – *Jacob Perkins' refrigerating machine*, 1834. *It had all the main features of the modern machine. The compressor* A *drew the vapour from the volatile liquid in the space* B, *causing heat to be extracted from the water and ice to be formed in the vessel* C. *The compressed vapour passed to the condensing coil* D *in which it was liquefied. Thereafter it passed through the expansion valve* E *back to the space* B.



(*a*)

(*b*)

FIGURE 2 – (*a*) *Quick freezing. Muscle structure in meat frozen completely in* 4 *minutes.* (*b*) *Slow freezing. Muscle structure in meat in which freezing has taken* 275 *minutes. For this purpose the period of freezing is the time taken to bring the temperature from* 5° *C to* – 5° *C.*

(From *Food Investigation Reports of the D.S.I.R.*, 1931.)

FIGURE 3 – *Slabs of quick-frozen boned beef prepared in England for shipment to war zones. These* 64 *slabs weigh* 2,009 *lb. and occupy* 37½ *cu. ft. A single carcase in the ordinary form weighs about* 700 *lb. and has up to* 100 *cu. ft. allotted to it. Thus shipping space is saved by boning, compressing, and quick freezing.* (*By courtesy of* Modern Refrigeration.)

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about 1845, the working substance being air, and because of its very uneconomical performance, arising from mistakes of a thermodynamic nature, it was not a marked success. James Harrison, an Australian, made a success of an ether machine in 1857, and Alexander Kirk about 1860 constructed, for work connected with paraffin extraction from shale distillates in Scotland, a practical air-refrigerating machine.

In the seventies much progress was made, largely because the thermodynamic principles underlying the process, which were established about 1850 by William Thomson (Lord Kelvin) and Macquorn Rankine, had then become more widely appreciated. It is not possible to sketch here in detail the many advances arising from the introduction of ammonia and carbon dioxide as working substances, and from the development of the method of the absorption and disassociation of the volatile substance to replace the compressor. Much credit is due to workers in continental Europe, such as the brothers Carré, Windhausen, and Linde.

USE OF COLD IN FOOD PRESERVATION

It was known long ago that if food is kept cool its edibility is prolonged. It is recorded of Francis Bacon that in March 1626, when driving near Highgate, he was taken with a desire to discover whether snow would retard putrefaction. He stopped his carriage, bought a fowl, and, with his own hands, stuffed it with snow. It is not known how the experiment went; but the result, it would seem, was disastrous to the experimenter, who died of a chill a week or so later.

The idea was not new. According to authorities, ancient Roman cookery-books have references to the covering of certain dishes with snow, the object of which could only have been preservative.

The use of the ice-box in preserving foods is no doubt very ancient, and the method is still widely used today. The first perishable foodstuff ever transported over a lengthy sea route was meat, which was preserved on board ship by means of ice mixed with salt and packed round the containers. At a later period, ice-cooled air was circulated in the meat chambers. This was in the 'seventies of last century, when the only import trade in chilled beef was from the United States to Britain. An early attempt to bring meat from Australia by this means was a failure. For such a lengthy voyage something more lasting than ice was needed. In 1877 a French ship carried a perishable cargo from the Argentine to France with fair success, although the voyage took 110 days. The ship carried an ammonia type of refrigerating machine on board.

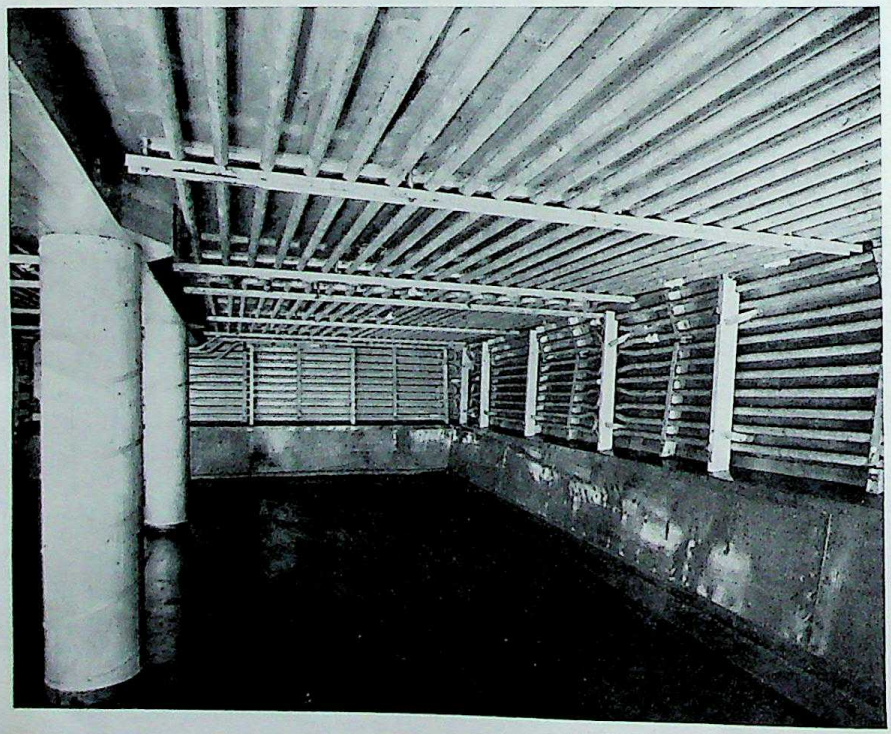

FIGURE 4 – *A corner of a cargo chamber in a ship. The great system of pipes carries brine, which itself has been cooled to a low temperature by the refrigerating machinery.*
(By courtesy of L. Sterne & Company Limited.)

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DEVELOPMENT OF BRITISH MARINE REFRIGERATION

We may assume that the experience of the ammonia machine had not been a happy one—as indeed it was not likely to be in the state of refrigerating engineering at that time—for the French abandoned the experiment and the field was left open.

Henry and James Bell, members of a firm of meat importers in Glasgow, were anxious to adopt some form of mechanical refrigeration on the ships carrying their cargoes, and consulted Lord Kelvin, who brought in James Coleman, a chemist who had experience of refrigeration in the shale industry. The upshot was the making of the Bell-Coleman cold-air machine, which was installed in the Anchor liner *Circassia* in 1879. She plied between New York and Glasgow, and the success of the venture may be taken for granted, for a second machine was fitted in the *Strathleven*, a steamer of 2,257 tons, which in 1880 brought 34 tons of frozen mutton and beef from Australia to London. A sailing ship, the *Dunedin*, fitted with the Bell-Coleman refrigerator, in 1882 brought the first 5,000 frozen carcases of mutton from New Zealand. Expansion of this trade was rapid. In the year 1874, by the old ice-box methods, 55 tons of meat were imported. In the year 1901, with the aid of refrigerating machines, 150,000 tons were imported from the United States alone, and in one month of 1939 a total of 90,000 tons of meat was brought in from all sources.

A similar trade in imported fruit sprang into existence, and developed rapidly when the technique of the proper care of fruit in storage had been worked out.

ECONOMIC RESULTS

The outcome of these new developments was startling. It led to an economic revolution, and Australia, New Zealand, and South America began to build up great economic strength. But the effects in the international field were not unaccompanied by unsettlement at home. A factional war was waged between opposing vested interests—the home producers of meat on the one hand and the importers on the other. An interesting light is thrown upon public feeling at this time by cartoons in *Punch*, which in the 'eighties still retained its early Radical complexion.

It may be accepted, with little qualification, that, without the import of refrigerated foodstuffs, a country like Britain could not at any time maintain its population of factory workers. British economic stability depends on refrigeration and, in time of war, so also does the national security.

Since 1880 standards of diet and the amenities of life have greatly improved. By the application of artificial cooling, fruits, for example, that were exotic and rare have, except for the interruptions of war, been made available to the masses of the population in Britain.

Let us try, for a moment, to forget our present somewhat unvaried menu and view dispassionately the peace-time record of marine refrigeration. In the month of January in the year 1939 Great Britain imported enough meat to give every man, woman, and child a weight of four pounds, enough butter to give everyone a pound and a half, enough oranges to give everyone a dozen, and, in addition, large quantities of eggs, bananas, grape-fruit, lemons, grapes, pears, plums, peaches, and apples.

The saving of perishable foodstuffs by cold storage on land stands in importance second only to marine refrigeration. This is of course especially true in time of war, and the Government has added to the nation's normal cold storage space by erecting in different parts of the country great refrigerated stores, which are possibly the best of their kind to be found anywhere.

COLD STORAGE TECHNIQUE

The solution of the mechanical problem of refrigeration was far from being the end of the matter. Alongside the engineer have worked the biochemists and bacteriologists, in the study of the behaviour of foodstuffs under different physical conditions. The work of the late Sir William Hardy, who had the combined attributes of the engineer, the chemist, and the biologist, gave to Great Britain the honour of leading the way in the comprehensive and scientific study of food preservation. His work with the Food Investigation Board at the Cambridge Low Temperature Research Station and elsewhere has become classical, and has inspired researches of inestimable value.

THE STORY OF THE APPLE

An example of the achievements of Hardy and his associates is the research on the behaviour of the apple in storage. Cargoes of apples carefully packed and kept at a temperature sufficiently low to retard the process of decay, though not to freeze them, were found at the end of a lengthy voyage to be unsalable because of brown-heart disease. Investigation of this effect led to an

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explanation which may be summarized as follows:

The apple, like all fruits, is a living organism, and its living processes do not stop when it is taken from the tree. It inhales oxygen and exhales carbon dioxide and water. The faster the respiration the shorter the time of ripening; the slower the respiration the longer the fruit will keep. Cold retards the life processes, but so long as respiration goes on, the atmosphere in which the apple lives is of importance. With carbon dioxide in the air up to a concentration of 12·5 per cent., the processes are slowed down and the time for which the fruit will keep in store is lengthened; but at higher concentrations the life flickers and disease takes its toll. Hence ships' holds in which apples are carried must be ventilated in such a way as to check the accumulation of the carbon dioxide exhaled by the apples themselves.

Freezing of apples is avoided in sea transport. Their freezing-point is about 29° F and they are usually held at about 31° F. Like all other substances containing water, apples lose weight if the relative humidity in the cold storage rooms is below a certain level.

COLD STORAGE OF MEAT

Meat kept at a temperature just above its freezing-point is called chilled meat. It does not as a rule keep for more than about 28 days, but up to that period it looks like fresh meat when exposed for sale. Frozen meat, on the other hand, is meat cooled to about 15° F; it remains edible for long periods. Following the experience with fruit, carbon dioxide was tried in the atmosphere of rooms containing chilled meat, and the experiment was a marked success. The keeping quality was greatly improved and the growth of moulds was largely inhibited. Previously, meat could be brought from so far away as Australia and New Zealand only in the frozen condition, but now, with the new 'gas storage' method, it can come as chilled meat.

EFFECTS OF SPEED OF FREEZING

When frozen meat is thawed it often exhibits the unpleasant feature called 'drip.' This may arise to some extent from the simple phenomenon which causes our water-pipes to be ruptured in a time of frost, but that is not quite the whole story, since the walls of the cells of the meat are elastic. If the rate of freezing is very slow, the ice crystal inside a cell may be enlarged by liquid diffusing through its walls from the outside until the walls are torn by the growth. On thawing, the juices

If the freezing is carried out very rapidly, however, by the application of a very low temperature, the unattractive 'drip' is found to be absent when the meat is thawed. This discovery has led to the application of methods of quick freezing to fish, meat, fruit, and vegetables, for with proper care the thawed foodstuff is found to be as fresh and pure, and to have the same natural flavour, as before storing.

The speed of freezing of beef is greatly increased by boning it, packing it into slabs, and compressing it between hollow freezing plates to which the low-temperature refrigerant is applied. This procedure is largely displacing chilled meat because of the great economy in shipping space effected.

EGGS AND OTHER THINGS

We have seen how fastidious the apple may be as to its conditions of storage, but the egg—though today we have reason to view it with respect—has always seemed to be rather dull and unresponsive. Yet the egg is the most temperamental of foodstuffs for the cold stores to handle.

Even a healthy egg when alive gives off gas, and if this is not continuously removed, fungus forms and the egg becomes musty. If the humidity of the atmosphere is not just right, it may, on the one hand, lose weight or, on the other, grow whiskers of mildew. And the temperature must not deviate by more than a narrow margin from 32° F. Eggs cannot be stored with other things, for they are susceptible to taint from the slightest odour. The greatest care must therefore be taken that they are stored by themselves in rooms which are not adjacent to others used for storing fruits and other produce. Butter must be kept in the dark if it is not to deteriorate in both colour and flavour. Every one of the innumerable kinds of perishable produce has its own whims and peculiarities.

CONCLUSION

The description of the many applications of mechanical refrigeration to matters other than the preservation of food must await another occasion. Sufficient has been written here to show that the engineer and chemist have in the development of refrigeration been responsible for a greater and more lasting revolution than any political figure or great dictator in history. And it has been a revolution which is bringing to men in ever-increasing measure easement, and sweetness, and health.

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Thomas Charles Hope, 1766—1844

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JAMES KENDALL

From the science of our schooldays, a few experiments are apt to be recollected with sharp clarity. One of them is Hope's experiment to determine the temperature of the maximum density of water. Perhaps it was not so much the elegance of the procedure as the extravagance of using two thermometers at the same time that impressed us. In any case, Hope 'springs eternal' in our memories, and Professor Kendall tells us what manner of man he was.

This year marks the centenary of the death of Thomas Charles Hope, F.R.S., Professor of Chemistry at the University of Edinburgh from 1795 to 1844. Though his fame is somewhat overshadowed by the superior achievements of his predecessor Joseph Black, Hope ranks as a noteworthy contributor to the progress of science. He was the first teacher in Great Britain to substitute the new doctrines of Lavoisier for the phlogiston theory in his public lectures; he isolated and named the first known compound of strontium; he first established the exact point of the maximum density of water; and he recommended Humphry Davy to the notice of Count Rumford as a suitable lecturer for the Royal Institution.

Hope's father was Regius Professor of Botany in the University of Edinburgh, and he himself entered as a student there at the precocious age of 13. As was natural, he devoted much attention to botany, and displayed such proficiency in this science that on his father's death in 1786 he was put forward as a strong candidate for the vacant chair. This was in accordance with the practice of the times, since for a record period of 126 years the sister professorship of anatomy was occupied by Alexander Munro (three successive generations, 1720–1846), but the young man of 20 was forced to wait another year before he was selected to fill a responsible academic position, the lectureship in chemistry at the University of Glasgow.

He was then, like his teacher in Edinburgh Joseph Black and all his British colleagues, a strenuous supporter of the phlogiston hypothesis of Stahl. His friend Sir James Hall, however, returned to Scotland in the autumn of 1787 from Paris, where he had been much in the society of Lavoisier, who exhibited to him several very important experiments not yet made known to the chemical world in general. Hall had many long discussions on the work of Lavoisier with Hope, and soon convinced him of the truth of the new ideas. That winter he taught them to his class, the first occasion on which the doctrines of Lavoisier were publicly promulgated in this country, and the following summer he himself spent in Paris, where the amiable manners and great abilities of Lavoisier made a strong and lasting impression upon him. As his biographer [8] remarks: 'Few persons more sincerely deplored the sad fate of that accomplished man, from whom he had received the most flattering attentions.'

In 1789, Hope obtained the appointment of assistant professor in medicine to his uncle Dr Stevenson in the University of Glasgow, and on the death of his uncle in 1791 became the sole Professor of Practical Medicine. He then resigned the office of lecturer in chemistry, but continued his private researches in his favourite study, the first result of which was a masterly paper on a mineral from Strontian, communicated to the Royal Society of Edinburgh in 1793.

In this article [1] Hope proved, what had been previously only conjectured by Crawford and others, that this mineral contained a peculiar 'earth,' differing decidedly in properties from barytes, with which it is associated. To this new earth Hope gave the name of *strontites*, from the village of Strontian, in Argyllshire, Scotland, at which it had been found. His original preparation (dated 1791) of what is now known as strontium hydroxide still stands in the museum of the department of chemistry at the University of Edinburgh: a clear saturated solution with a fine crop of crystals at the foot, as shown in figure 2. Several other chemists have claimed the credit for the discovery of strontium (the metal itself, it may be noted, was first isolated in 1808 by Humphry Davy), but critical examination of the literature justifies the statement of Traill [8]:

> The only chemist who has the slightest claim to the merit of an original detecter of Strontium earth, besides Dr Hope, is M. Klaproth, who, in the

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Chemische Annalen for 1793–94, compared Strontian with witherite. He reconciled himself with some regret to this limitation, and among his private papers there was found after his death the following interesting statement:

> Those who devote themselves to the science of chemistry may be divided into two classes. 1st, Those whose labours are employed in original researches, to extend our knowledge of facts and principles. 2dly, Those whose business it is to collect the knowledge of all that has been discovered or is going forward, to digest and arrange that knowledge into lectures, to contrive appropriate and illustrative experiments, and devise suitable apparatus for the purpose of communicating a knowledge of chemistry to the rising generation, or others who may desire to obtain it. From my professional situation I consider myself, *as Dr Black had done before me*, as belonging to the second class of chemists. I consider my vocation to be the teaching the science.

Some time, nevertheless, he did manage to set aside for research. In 1804 he presented an important memoir to the Royal Society of Edinburgh on the contraction of water by heat at low temperatures [2]. As long ago as 1667, the singular fact had been noted by the Florentine academicians that water expands as it cools towards its freezing-point, and Croune had shown this phenomenon to the Royal Society of London in a Gresham Lecture in 1683. Several subsequent investigators had endeavoured to determine the exact temperature at which water attains its maximum density, but could not derive consistent results. All their experiments were made in tubes with large bulbs at one extremity, like huge thermometers.

It was contended by Hooke, after the delivery of Croune's lecture, that the expansion observed was only apparent, not real; arising from the sudden contraction of the material of the bulb on the application of cold. This opinion was still held more than a hundred years later by many eminent chemists, including Dalton, who carried out a series of inconclusive experiments on the phenomenon and finally drew Hope's attention to it in a private letter. Hope settled the question for ever by experiments in which a change in the capacity of the containing vessels could have no influence on the results.

He took a cylindrical glass vessel, $8\frac{1}{2}$ in. deep and $4\frac{1}{2}$ in. wide, which was filled with water at the freezing-point, 32° F. Two delicate thermometers were suspended in the vessel, the bulb of one being half an inch below the top of the liquid and that of the other as far from the

tianite with Witherite. Neither Klaproth nor Hope seems to have been aware of what the other had discovered, and both may therefore be considered as original discoverers, but the first full investigation of the subject is undoubtedly due to Dr Hope.

This brilliant research, and the popularity of Hope's chemistry teaching at Glasgow, suggested to Joseph Black, then in declining health, the idea of securing his promising pupil as his assistant and successor in the chair of chemistry at Edinburgh, and in November 1795 the patrons chose Hope in that capacity. In the following session, Black found it necessary at last to relinquish his long-famous lectures and introduced Hope to his class in the following terms:

> After having, for between thirty and forty years, believed and taught the chemical doctrines of Stahl, I have become a convert to the new views of chemical action; I subscribe to almost all M. Lavoisier's doctrines and scruple not to teach them. But they will be fully explained to you by my colleague and friend Dr Hope, who has had the advantage of having them from the mouth of their ingenious author.

On Black's death in December 1799 Hope became the sole Professor of Chemistry at Edinburgh University.

That position he held for forty-five years. The variety and excellence of his illustrations, and his dexterity in chemical manipulations, made him the most popular teacher of the science that had ever appeared in Great Britain.

> Not only was his lecture-room crowded with medical students from every part of the British dominions, but numerous foreigners resorted to Edinburgh and became his pupils. The large class-room was filled to overflowing, and he who was not there before the commencement of the lecture had no chance of a seat.

That this quotation [8] is no exaggeration is shown by the fact that the average attendance at Hope's lectures increased from 225 at the time of his appointment to 575 in 1827; the total number of tickets issued for his chemical course during his tenure of office was no fewer than 16,800. In 1838, on the completion of his fiftieth year as a professor of chemistry, he was invited by a numerous body of his former pupils to a public dinner, at which he stated that he had never been, either as a student or as a teacher, detained from the duties of his class, except for *six days by indisposition.*

Such scrupulous attention to academic responsibilities inevitably restricted Hope's output of research to a minimum during the period of his

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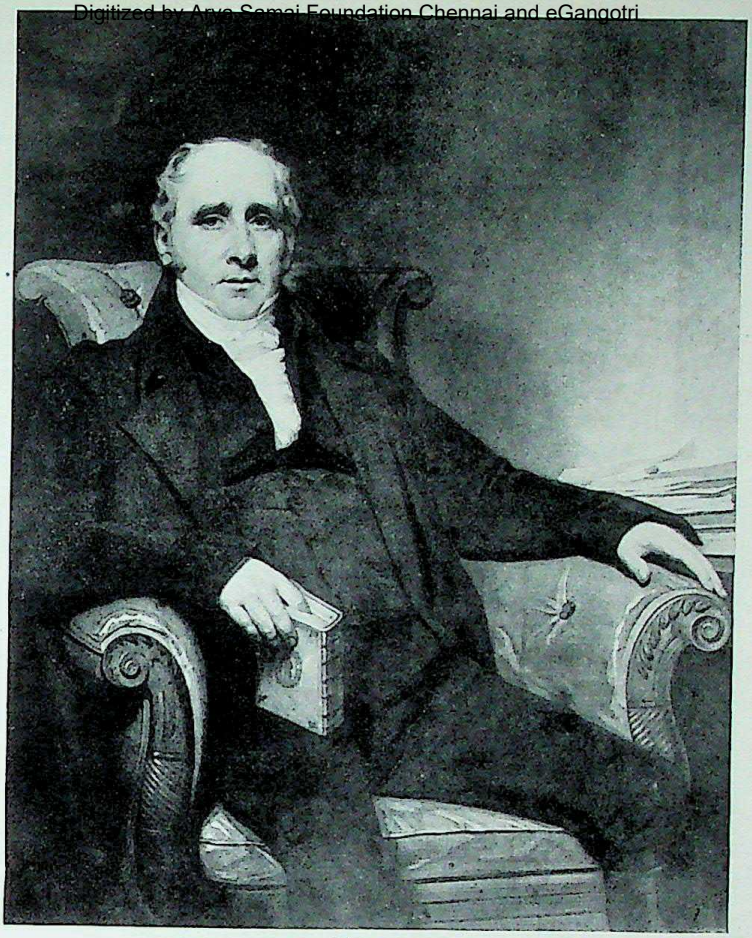

FIGURE 1 – *Thomas Charles Hope.*
(From a painting by Raeburn.)

bottom. The apparatus was placed in a room at a temperature of 60°, and the progressive changes in the temperature of the water were carefully noted on both thermometers. From 32° to 38°, the lower thermometer was invariably higher than the upper; a proof that throughout this interval the water was becoming more dense as the temperature rose. On reversing the experiment by placing water at 53° in an environment cooled to 32°, Hope found that while the temperature of the water was falling to 40°, the water at the bottom was always the colder, but that in cooling from 40° to the freezing-point, the thermometer at the bottom remained higher than that near the surface.

The temperature of the maximum density of water was thus established as lying between 38° and 40°; Hope's final value, after he had varied his technique in different ways, was 39·1°. This is in good accordance with the modern figure of 39·2° F (3·98° C).

Dalton admitted the accuracy of Hope's observations, but a long note attached to the main paper failed to convince Count Rumford that Hope had also demonstrated conclusively the fallacy of his theory that liquids were absolute non-conductors of heat. It is rather strange that Rumford should have hesitated to acknowledge Hope's scientific acumen, since he was directly indebted to him for the discovery of Humphry Davy. Passing through Bristol in 1799, Hope visted Dr Thomas Beddoes, who had been his fellow-student at Edinburgh and was, indeed, one of the original members of the Chemical Society of the University of Edinburgh in 1785 [6]. In Beddoes' laboratory at the Pneumatic Institution, he found the twenty-year-old Davy immersed in his experiments on nitrous oxide, and was deeply struck by his originality and inventive genius. Soon afterwards, Hope was consulted regarding a 'lecturer of talent' required by Rumford for the Royal Institution; he strongly recommended

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Davy to the notice of the Court and Davy received the appointment. Never in the history of chemistry was a recommendation more richly justified by subsequent results.

Hope also evidently made an impression on Davy. Unable to realize his own cherished ambition to obtain an Edinburgh degree, Davy sent his younger brother (and future biographer) John to be trained as a chemist in Hope's laboratory. It was there that John carried out a series of decisive demonstrations upon the elementary nature of chlorine to refute the criticisms of Murray on Humphry's work.

In 1826, at the ripe age of 60, Hope emulated Davy's social triumphs at the Royal Institution by instituting 'a short course of chemical lectures for Ladies and Gentlemen.' His vast lecture-room was packed with a most brilliant audience; and he gave the proceeds—a sum of £800—to the Senatus Academicus to establish a prize 'to the author of the best essay on a given chemical subject, illustrated by experiment.' This fund has since been augmented, and five Hope Prize Scholarships are now awarded annually to deserving Edinburgh students of chemistry.

Hope never married. His department was his wife, his pupils were his family. His very chair serves as a support to his present successor while he writes this article; it is not perhaps as inspiring as that of Joseph Black, which stands opposite it, but it is certainly more comfortable. His portrait, from a painting by Raeburn, is shown in figure 1. When George IV visited Edinburgh in 1822, the patriotic fervour of the Scots induced such a run upon representations of his royal figure that engravings of this picture, with the sash of the Order of the Garter across the chest as the sole alteration, were utilized to fill the local deficiency. These 'false Hopes,' according to information received some years ago from Sir James Walker, are now very scarce and command a high price. History does not disclose who was the more flattered by the incident—Hope or George IV!

FIGURE 2 – *Hope's original preparation of strontium hydroxide.*

Long after the latter's reign was ended, however, his scientific double continued his chemical activities. Hope delivered his last series of lectures in 1843. In the spring of the same year, at the age of 77, he blossomed out anew as a research worker in three communications to the Royal Society of Edinburgh, of which body he was then a vice-president. Two of these [3] [4] dealt with the constitution of the colouring matters in the leaves and flowers of plants, the third [5] discussed the temperature phenomena of the famous freezing cavern at Orenburg. With the coming of autumn, Hope's health deteriorated; he passed away on 13th June, 1844. His friend Dalton died only a few weeks later.

One human touch, for which I am indebted to my teacher and colleague Dr J. E. Mackenzie [7], may be added to conclude this memoir. During one of Hope's lectures, an unruly student threw a handful of peas at the professor and some struck him in the face. He started to reprimand the offender in dignified language, but suddenly lapsed into broad Scots as follows: 'Such conduct is unbecoming of a gentleman and moreover — it's daumed sair!'

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[4] *Idem.* 'Observations on the Flowers of the Camellia Japonica, etc.,' *Proc. roy. Soc. Edinb.*, 1845, **1**, 419.

[5] *Idem.* 'An Attempt to explain the Phenomena of the Freezing Cavern at Orenburg,' *Proc. roy. Soc. Edinb.*, 1845, **1**, 429.

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ROTATION OF THE GALAXY

Stellar Dynamics and Galactic Rotation, *by S. W. Shiveshwarkar. Pp. iv + 171. Lucknow University Studies No. xvi.* 1943.

Stellar dynamics is concerned with the spatial and velocity distribution of the stars in a system at every point of space and time. The methods are necessarily statistical, as it is not required to trace the motion of the individual stars. The study of steapy states of stellar systems is of particular interest. Though there is a close analogy between a stellar system and a gas, there is the important difference that close passages or collisions between stars are rare, whilst the molecules in a gas are in frequent collision. In a stellar system the law of attraction between individual members of the system is known to be the inverse square law. The pioneer investigations of Jeans, Eddington, and Charlier established a number of results of wide generality. The application of the methods of stellar dynamics to the rotating Galaxy is of interest, and enables some conclusions about the distribution of matter in the Galaxy to be derived. The phenomena of star streaming and of the asymmetrical drift of the high-velocity stars are both accounted for, but there is a discordance of some 20° between the observed and the theoretical directions of the star streaming. Shiveshwarkar shows that this may be explained on the assumption of a galactic expansion; but this is not necessarily the true explanation, and it has been criticized by Lindblad and others. Motions along spiral arms, as in a spiral nebula, may be involved.

This little volume provides an excellent concise summary of the main results in this field. Full bibliographical references are given. The volume is well printed and the type is clear.

H. SPENCER JONES

THEORY AND PRACTICE OF OPTICAL GLASSWORKING

Optical Workshop Principles, *by Charles Dévé, translated by T. L. Tippall. Pp. xiv + 306. Adam Hilger Limited, London.* 1943. 20*s. net.*

Messrs. Adam Hilger and the translator have performed a useful service to English-speaking opticians by the publication of this book, which was not well known in this country, although the original French text was published from the *Institut d'Optique* in Paris in 1936. It embodies much original discussion of the theory of optical grinding processes, and is the only treatment known to the writer in which the kinematical aspect of the subject is adequately considered. Its perusal cannot fail to be helpful to those who wish to short-circuit, or improve upon, the necessity for a long period of learning by example rather than precept.

The translation is, for the most part, happy, and few difficulties arise; but there are a number of passages in which, even in the original text, the argument is too condensed, and the present writer found it necessary to read certain passages several times before the meaning became clear, partly, perhaps, because the translator has adhered too closely to a rigid translation. For example, a sentence on p. 116 begins: 'The most general movement of a disc which is displaced on a stationary plate, guiding it by a central knob, is . . ., etc.' Now the meaning is clear enough on analysis, though the grammar is questionable; but the language might have been chosen to convey the meaning in a more vivid fashion. If the translator had spoken of 'a disc which, guided by a central knob, is sliding upon a stationary plate,' he would have caused no difficulty. A little later we are told 'The curve of rolling increases,' but cannot tell without analysis whether this refers to curvature in the mathematical sense or to radius of curvature.

It is not, of course, to be expected that this book will reflect details of technique which have been introduced during the present war, but if a good basic text is desired, it will go a long way towards meeting the need.

L. C. MARTIN

DICTIONARY OF ORGANIC COMPOUNDS

Dictionary of Organic Compounds, Volumes II and III, *edited by I. M. Heilbron and H. M. Bunbury. Pp. viii + 891 and viii + 977. Eyre & Spottiswoode Limited, London. New, revised, and enlarged edition,* 1943. £6 6*s. net each volume.*

War conditions have prevented the comprehensive revision of Volumes II and III of this Dictionary on the same lines as Volume I (reviewed in ENDEAVOUR, **3**, 43), and these two volumes have been reprinted unchanged but with the addition of Supplements. These comprise 42 and 32 pages respectively. They deal mainly with recently investigated natural products (particularly alkaloids), polynuclear aromatic derivatives, and heterocyclic compounds, together with many cross-references to the other volumes. Literature references in these supplements cover the period up to 1942, but quite a number of compounds appearing therein carry references only prior to 1920. These, presumably, represent omissions from the first edition.

The task of bringing these volumes up to date must have been a difficult one under present conditions, and the collation of recent literature references thus made available is extremely valuable to all organic chemists. In view of the relatively small content of the supplements, however, it would have been a great advantage to those who already possess the earlier edition if these supplements could also have been published separately, pending the more comprehensive revision of the Dictionary as a whole which should become possible with the return of normal conditions.

J. W. BAKER

METALLURGY FOR THE MILLION

Metals in the Service of Man, *by William Alexander and Arthur Street. (A Pelican Book.) Pp.* 192. *Penguin Books Limited, Harmondsworth and New York.* 1944. 9*d. net.*

The beginnings of the art of extracting and working metals are lost in the mists of antiquity, yet the light alloy industry is of very recent origin and has opened up great new fields of usefulness. The marvellous way in which the properties of metals can be modified by the addition of proper alloying elements is among the outstanding achievements of modern times. The authors hope that this book 'will be of interest to the many who handle metals in their daily work, and perhaps also to those whose closest acquaintance with them is the keys of a typewriter or the parts of a rifle.' Although it is not intended to be a profound contribution to the literature of metallurgy, the authors have not hesitated to include discussions of scientific advances where these are of real importance in the use of metals. For example, the development of X-ray methods of structure analysis has provided metallurgists with their most

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powerful tool for the investigation of the metallic state. This fascinating volume deserves a wide public, for the writers have succeeded in presenting the accomplishments of a great industry with sound scholarship, enthusiasm, and charm. W. WARDLAW

ULTRA-FINE STRUCTURE OF COALS AND COKES

Proceedings of a Conference on the Ultra-fine Structure of Coals and Cokes, held at the Royal Institution, London, 24th–25th June, 1943, *by the British Coal Utilization Research Association. Pp.* 366. *H. K. Lewis & Company Limited, London.* 1944. 25*s. net.*

Sir Evan Williams, in the foreword to the *Proceedings*, suggests that we are entering upon an era in which great industries based on the use of coal as a chemical raw material may be developed. Such a view stresses the importance of long-range and fundamental investigations into the properties of coal and the utilization of coal resources. Therefore, in order to ensure success, two different groups of people were invited to the conference, viz. those concerned with the production and use of coal on the one hand, and scientists from the universities and technical colleges on the other. It is agreed that the Conference represented a bold experiment, because the problems chosen were difficult, and the majority of the twenty-two papers presented dealt with fundamental work on some aspects of structure such as, for example, the colloidal and internal structure of coal.

X-ray diffraction technique and the electron microscope were both called upon to help, while the infra-red spectrum, and optical, magnetic, and electrical properties, were among the other angles of attack.

In most cases the papers are followed by a bibliography and details of the discussion. In addition to author and subject indexes, there are some 119 figures, mostly graphs, about 70 tables of data, and 14 full-page plates excellently reproduced, the whole constituting a volume which all interested in the utilization of coal should peruse with care. ARTHUR MARSDEN

THE CHEMISTRY OF HORSE-DOPING

Notas Microquímicas sobre 'Doping,' *by Dr. Enrique Herrero Ducloux. Pp.* 265. *Peuser Lda, Buenos Aires.* 1943.

Some years ago, the racing committee of the Buenos Aires Jockey Club appointed a group of experts—chemists, physicists and veterinary surgeons—with a jurist as president, to provide a scientific basis for a system of control over horses entered for racing events. In that connexion, the author investigated methods of detecting 'dopes,' and this book records his results.

He confines attention to the formation of crystalline precipitates of derivatives of the drugs used, provides descriptions of reagents found useful, with notes on the concentrations at which they are effective, and gives nearly 200 excellent microphotographs of crystalline preparations yielded by the thirty-eight drugs selected. For confirmatory tests, such as the usual colour reactions, he refers the reader to the bibliography of toxicological text-books provided, but includes a short descriptive monograph on each drug.

A 'dope' is defined as 'any chemical or physico-chemical agent administered before the event to a racing animal with the object of influencing its locomotive power and eventually its speed.'

The range of drugs dealt with is evidence of the ingenuity and up-to-date pharmacological knowledge of the purveyor of 'dopes.' Not only are the expected stimulants, sedatives, and poisons included, but also substances influencing glandular secretion and body temperature, and harmless materials, such as urea, intended to mislead the chemical investigator.

T. A. HENRY

STANDARD BIOLOGICAL PREPARATIONS

Biological Standardization, VI (Bulletin of Health Organization). *Pp.* 80. *Allen & Unwin Limited* (*League of Nations Publications Department*), *London.* 1942–43. 4s.

The League of Nations still survives, and its Health Organization has now published another number of its Bulletin. The international co-operation in this field has proved probably the most lasting and the happiest of all, and to medical science it has been of great value. Biological standardization, involving as it does agreement about standards and units of measurement of therapeutic agents, is an obligatory interest for all countries, and on its account many co-operative investigations have been arranged and completed.

The Bulletin just issued deals in the main with the replacement of the standard preparations collected by international agreement before the war, and now becoming exhausted. For extract of the posterior lobe of the pituitary gland, for example, there has been a stock of dried posterior lobe kept at the National Institute for Medical Research at Hampstead, for distribution to workers in any part of the world on demand, to be used as a standard with which to compare in potency freshly made samples. The replacement of the stock as it becomes exhausted involves much labour, for the new standard is distributed to a great many workers to get their opinion of the relation between the new and the old standards. By taking an arbitrary mean of these opinions the relation is established. This kind of work has been done for many substances: for the standards for the oestrus-producing hormone, for male hormones, for the progestational hormone of the corpus luteum, and others. The Bulletin also contains an account of work on standard preparations of the three gas gangrene antitoxins and of heparin. On account of this work, great progress throughout the world in the development of therapeutic substances has been made possible.

TREATMENT OF NEMATODES IN LAMBS

Co-ordinated Trials with Phenothiazine against Nematodes in Lambs. *Imperial Agricultural Bureaux, Joint Pub. No.* 4. *Agricultural Research Council of the United Kingdom, London.* 1943. 3*s.* 6*d.*

This report is interesting not only for the results obtained but also for the methods which were used. The experiments were planned so that statistical procedures could be applied to the results obtained at a number of different centres, and the report contains an account of two new developments of existing statistical procedures. Evidence from inside flocks indicated that the greatest relative reduction in egg-count was caused by the lowest (5 gr.) dose used. Evidence from outside flocks was that, while egg-count reductions had been obliterated by reinfestation (except in flocks grazed on clean pasture), there was a relatively large weight response in the treated lambs, which increased roughly in proportion to dosage up to the highest dosage used (50 gr.). From these results it is suggested that the action of phenothiazine may lead to a reduction not only of stomach worms but also of certain intestinal worms usually considered of little clinical importance.

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ENDEAVOUR
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of the sciences in the service of mankind

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The meaning of science

The century in which we live has witnessed an advance in man's command of the material universe unexampled in the previous history of the world. Indeed, it has been asserted by an eminent sociologist that the progress of the last forty years equals, and perhaps surpasses, that of the whole period of human history from the dawn of civilization up to the year 1900. The nations of the world now have at their disposal unparalleled power over natural substances and forces—a power which has been placed in their hands by the expansion of scientific knowledge, and which may be used for good or for evil purposes. Whether man has reached a stage in his moral evolution at which he can be trusted to turn these gifts to predominantly beneficial ends is a matter with which we are not for the moment concerned.

Concurrently with these advances in applied science has come a reformulation of fundamental theories. This has altered our concepts of that world-model which is sometimes naïvely taken to express the ultimate reality of things, and altered them in a manner that can only be described as revolutionary. It has also fostered a tendency to ask the questions 'What is meant by the term science?' and 'What are the objects and scope of a scientific theory?'.

Our nineteenth-century forbears had a simple answer to the first of these queries. Science to them was just 'organized common sense,' and inasmuch as their very successful physical theories were an extrapolation of large-scale mechanical notions to cover atomic phenomena the answer may be deemed to have been adequate at that time. But in these days of quantum mechanics and probability-smears the answer to the same question is not expressible with similar simplicity. What, then, are the aims and objects of the man of science in his quest for truth—or what he regards as truth? The reply to this second query may be found to include that to the first.

We have our being in a jungle of sense-impressions. The stars wheel in majestic circles around the pole; the planets move with apparent irregularity amid the so-called fixed stars; the tides ebb and flow; the barometer rises and falls; April showers pierce to the root of the drought of March; figs do not grow on thistles; a respectable law-abiding citizen suffers a brain injury and becomes an irresponsible criminal: these are but a scattered few from thousands of facts which meet us on our journey through life, and which, our minds being what they are, demand a coherent explanation. It is the object of science to give that explanation; though whereas our ancestors were wont to attempt to answer the question 'Why?' the man of science is today content if he can describe the 'How?' of the particular phenomenon in which his interest lies.

Newton, indeed, has the root of this matter in him. His famous *Hypotheses non fingo* must be read in its context if we would grasp its true significance: 'But hitherto I have not been able to discover the cause of those properties of gravity from phaenomena, and I frame no hypotheses; for whatever is not deduced from the phaenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy. In this philosophy particular propositions are inferred from the phaenomena, and afterwards rendered general by induction.'

Restricting ourselves to the consideration of the physical sciences, let us for a moment review the implications of a scientific theory. The great structure of nineteenth-century physics was based on Newtonian mechanics, which gave clear and precise definitions of such concepts as mass, force, momentum, energy, and the like. The laws of

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dynamics based on these concepts sufficed to describe with almost incredible accuracy an extraordinarily wide range of phenomena, from the motions of the planets down to the behaviour of the balls on a billiards table.

The scheme was extended into a conceptual submicroscopic world of atoms, and served to describe certain large-scale phenomena and to predict others, again with an accuracy that may be restrainedly designated as marvellous. The pressure of a gas, for example, was interpreted and calculated in terms of the movements of its molecular constituents; and whereas common observation shows that the viscosity of a liquid decreases rapidly with rise of temperature, the kinetic theory of the billiards ball atom predicted an increase of viscosity in a gas as the temperature rises—a prediction that was later confirmed by experiment. Such instances might be multiplied almost indefinitely, and it is small wonder that the rank and file of nineteenth-century scientists —and indeed some of the leaders—were convinced that their atoms were as real as the benches and Bunsen burners in the laboratories.

So with the ether of space. Lord Kelvin said with characteristic vigour: 'This thing we call the luminiferous ether . . . is the only substance we are confident of in dynamics. One thing we are sure of, and that is the reality and substantiality of the luminiferous ether.' But alas! for such optimism. We are not so convinced today of the reality and substantiality of a luminiferous ether as was Kelvin. Even our concept of the atom has become complicated almost out of recognition and bears no resemblance to the perfectly elastic, spherical atom of the Newtonian epoch.

In truth, a scientific theory is concerned with phenomena rather than with any 'reality' that may be supposed to lie behind them; its object, as Kirchhoff put it, is to describe, in the simplest possible fashion, the happenings in the physical world around us. If we can by means of a scientific theory correlate known facts and predict new ones the theory will have done for us all that a theory can do or is expected to do. Scientific theories have no permanence. They change with each generation and with a wider knowledge of perceptual facts; but—and it is a 'but' that the lay mind too frequently fails to appreciate—each new theory subsumes the one it displaces, in the sense that it is merely a closer description of the same phenomena or a wider generalization embracing a greater number of phenomena.

It cannot be denied that, in the middle years of the nineteenth century, there was a phase of scientific materialism which for some time had a considerable vogue. England and Germany were the countries most affected; but even they were not entirely swept by the movement, and wiser judgments were soon uttered by leading scientists. The privates in the scientific army may have been given an ingenuous realism, but the staff in general held clearer views concerning the limitations of a scientific theory.

Science, then, is concerned with phenomena, that is, with appearances. Working on this principle it has effected conquest of a large part of the material environment within reach, and shows every prospect of conquering much more. Whether pursuance of the same principle may lead to a knowledge of 'reality' is a question to which the answer is not yet even dimly perceptible. As Sir James Jeans has more than once emphasized, science in its present stage of development can be compared, for all its marvellous accomplishments, to the babe's first nebulous awareness of its surroundings. It may know many more pebbles than Newton, but it still knows little of the beach, and less of the ocean.

'Reality,' if it is to be discussed at all, must for the present be discussed as a philosophical problem, and the scientist as scientist need not adventure into such regions. For him a theory is merely a conceptual model of perceptual facts; it is, in the wise words of Sir J. J. Thomson, a tool rather than a creed. That should be a matter of satisfaction, for when the scientist looks around him at the monument he has erected, he might be forgiven if, of much other speculative thought, he murmured the sentiment of Omar Khayyám:

'Myself when young did eagerly frequent
Doctor and Saint, and heard great Argument
About it and about: but evermore
Came out by the same Door where in I went.'

Contributions and correspondence should be sent to the editor: E. J. Holmyard, M.A., M.Sc., D.Litt., F.R.I.C., Imperial Chemical Industries, Nobel House, Buckingham Gate, London, S.W.1. Scientists engaged in research of an interesting or important character are invited to send short notes on work in progress and results obtained.

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Meteorites and some of the problems which they present

LORD RAYLEIGH

The ancient Egyptian, Assyrian, Sumerian and Hebrew names for iron all signify 'the metal from heaven,' thus indicating that the earliest known specimens of iron were of meteoric origin, and, further, that the fall of meteorites had been observed. Lord Rayleigh describes the two principal kinds of meteorites, namely those composed chiefly of iron and those of a stony nature, and offers experimental evidence bearing upon the origin of the rare intermediate type containing both iron and stone in roughly equal amounts.

The history of this subject is most instructive for the philosophy of discovery generally. The scientific movement of the seventeenth century which is associated with the foundation of the Royal Society, the Paris Academy of Science, and the Accadèmia del Cimento in Florence was in part directed to the impartial investigation of alleged marvels, to see what measure of truth there might be in them. Thus we learn that the Royal Society at one of its early meetings arranged some powder of the horn of a unicorn in a ring on the table and placed a spider inside, in order to observe whether it could get out. It did so without difficulty, and the supposed marvel was discredited by the evidence of experiment. (The unicorn's horn was probably a narwhal's tusk.)

The general experience of those who have examined marvellous stories with cold scientific scrutiny has been the same. The great majority of such stories break down under investigation. It is often difficult to understand how they arose, but there can be no doubt that a large proportion of untutored minds delight in the marvellous and are disposed to accept it very uncritically. The difficulty of finding out the exact truth about any physical happening is much underestimated. In particular, no clear distinction is made between what was observed and what was inferred. It is largely by relying on this intellectual weakness that the conjurer makes his living.

It would be too summary to say that these early inquiries into the marvellous always led to a negative result. Joseph Glanvil, for example, an early Fellow of the Royal Society, looked into the question of witchcraft, and arrived at the conclusion that the evidence in favour of the belief was overwhelming. There is no reason to doubt that he had made an honest attempt to arrive at the truth. On the whole, however, the result was usually to discredit marvellous stories and by another very ordinary weakness of human nature, a premature generalization began to be formed that all such stories were untrue, and that it was a sign of mental superiority to reject them without examination. Considering the limitations of human life and effort, it can hardly be laid down that all alleged marvels deserve to be examined. In the last resort, individual judgment and inclination must decide: and most scientific men at the present time are not unwilling to examine into the marvellous if it comes their way. If they agree to do so, and if they see reason to reject it, they must be prepared to be considered perverse by the obstinately credulous.

Stories of the fall of stones from the sky were emphatically classed with the marvellous, in spite of the fact that numerous traditions of such occurrences existed, including some in the Bible and others in the classical authors. There must have been an appreciable number of falls during the Middle Ages, but, owing to lack of facilities for travel, lack of interest in science, and possibly also a general belief that miracles more interesting and significant than this one occurred fairly often, the available data were not collected or systematized. Much more interest was taken in the spurious bone of a saint than in a stone which had really fallen from the sky. It was only when mediaeval conditions began to pass away that this state of things was changed. The earliest known specimen of a meteorite actually seen to fall is preserved in the parish church of Ensisheim in Alsace. It fell in 1492.

It was long, however, before the scientific world became convinced; and this was no doubt due to the sceptical bias which was a necessary condition for the birth of the scientific movement.

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The French Academy of Science received in 1772 a report on a stone said to have fallen at Lucé a year or two before. Lavoisier was a member of the reporting committee. They considered that the stone was an ordinary stone which had been struck by lightning. It was not till many years later that the sceptics were finally silenced. A very large number of stones was reported to have fallen at L'Aigle in France on 26th April, 1803, and the Academy dispatched the well-known physicist Biot to investigate. His report finally settled the controversy, and he was even credited with the discovery, though it would be more correct to say that he broke away from the fashion of disbelief.

Once it is admitted that the falls actually occur, the question naturally arises: What is their real frequency? This is not an easy problem to resolve. In most places there is no one to observe a fall when it does occur, and it would evidently be most unsafe to attempt to estimate the probabilities of its being picked up afterwards. The only method which seems to give a reasonably trustworthy indication is to count the falls which actually occur on buildings, and then to estimate the fraction of the whole territory which these buildings cover. In this way it has been estimated that perhaps 250 falls occur in the United States per annum. No great reliance can be placed on this estimate, though it is probably of the right order of magnitude. Occasionally there have been falls of enormous meteorites which must have forced themselves on the attention of any observer who was within hundreds of miles of the spot. In various parts of the earth there are craters which are believed to mark the site of such falls (figure 1). Dr L. J. Spencer, formerly Keeper of Minerals in the British Museum, has devoted special attention to this subject, and has collected the available information. As might be expected, desert regions are favourable for the preservation of such craters, for in these regions the action of water and vegetation is at a minimum. If we recall how soon wasted areas in France and Belgium, covered with enormous shell-holes during 1914–18, recovered their normal aspect after a few years, we shall perhaps not be surprised that the meteor craters are only well discernible in areas where there is little water and little vegetation. The gigantic Siberian meteorite of June 1908, which fell at a distance of some 400 miles north-east of Lake Baikal and which produced a column of fire visible from 300 miles away, is perhaps the largest fall of which we have a dated record, but after a lapse of some twenty years it was found that the craters had largely fallen in and become filled up. In no case has a meteorite been located inside the crater, though in several instances numerous fragments have been found outside it. Mainly for this reason, Dr Spencer has urged the view that the crater results not directly from the impact, but from the explosion of steam or other vapours which result from the burial of the heated mass.

It has been suggested that the craters on the moon are of meteoric origin, and this view has found favour with some writers of authority. There is, however, an objection to it which I have not seen noticed. R. W. Wood has found that a region near the crater Aristarchus appears much darker when photographed through a screen transparent only to ultra-violet light (figure 2), and has come to the conclusion that this appearance is best explained by supposing that the rock is coated with a slight deposit of sublimed sulphur. Rock artificially treated in this way gives the same result. Sulphur is of course associated with volcanic activity, and the evidence seems rather strong that this particular crater, at any rate, is of volcanic rather than of meteoric origin.

But the questions have perhaps been too long delayed: What are the peculiarities of meteorites, and to what extent do they differ from materials normally found on the earth's surface or in mines? Can we distinguish a meteorite from all ordinary geological specimens?

A common delusion should first be cleared away. The heavy spherical balls occurring on the south coast of England, and found on fracture to possess a radiating structure of metallic aspect, are often popularly imagined to be 'meteorites.' They are nothing of the kind. These balls consist of marcasite, a form of iron sulphide, and occur embedded in the chalk cliffs where they originated. They are released by weathering, and in some places are quite common on the seashore at the base of the cliffs.

Of genuine meteorites there are two principal kinds, iron and stony meteorites; though, as we shall see presently, there is every intermediate gradation between these extreme types. The iron meteorites are far the commonest in museum collections, but there is reason to believe that in this respect the collections are by no means representative of Nature; for among falls actually recorded at the time of the occurrence, the stones

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are much commoner than the irons. If a meteorite is seen to fall, it is of course dug up and examined with eager curiosity, and without regard to preconceptions as to what a meteorite ought to be like, so that no particular kind is specially favoured. But if a meteorite is identified as such by its own characteristics, it is obvious that any observer, whether specially skilled or not, is much more likely to notice a mass of iron as being something out of the ordinary than to draw the same conclusion about a piece of stone. The latter may perhaps not be very difficult to distinguish from the stones of the district; but these last are often quite varied, having been conveyed for long distances by geological agencies such as ice or water. Hence it would indeed be rash to jump to the conclusion that an unusual kind of stone was a meteorite. On the other hand, if we meet with a mass of iron identified in the first instance by its weight, its coldness to the touch, and its behaviour under the file, and not bearing signs of artificial origin, we shall not often be wrong in concluding that it is a meteorite, for terrestrial iron found as such on the earth's surface is of rare occurrence. There are indeed a few cases where masses of free iron have been found, which are judged not to be of meteoric origin. The most conspicuous example is provided by those which were found by N. A. E. Nordenskiöld, the famous explorer, who was the first to traverse the North-East Passage; the site was Ovifak, Disco Island, Greenland, and the most recent view is that these masses were reduced from sulphide of iron by the action of carbon originally derived from the coal measures. In general, however, the earth's surface is too damp a place for free iron to survive for long, and this is one of several reasons for thinking that, whatever the circumstances of origin of meteorites, water was absent from the scene.

There are various instances of meteoric iron having been used by primitive peoples who did not practise the reduction of this metal from its ores. The references in Homer to iron as a rare and precious substance are perhaps best explained in this way. Iron ore is abundant, and if the reduction were practised at all it is not apparent why the product should be so scarce. On the other hand, meteoric iron is a very scarce substance indeed, and even now, when the earth's surface has been more fully searched, it commands large prices from collectors.

Meteoric iron differs from terrestrial iron in some important respects. One of the most striking points is that meteorites, broadly speaking, consist of one single crystal even if the meteorite weighs tons. In this respect meteoric iron differs entirely from any samples of iron which have been produced in industry, though it is true that some other metals, e.g. aluminium, have been produced in large single crystals in the course of experimental study. When we speak of single crystals, there is no reference to the presence of external crystal faces. The external surface of an iron meteorite is in fact rough and of irregular outline. What is meant is that there is a general tactical order and regularity prevailing without major discontinuity throughout the whole mass.

It would, however, be wrong to suppose that there are no minor discontinuities. The specimens of iron meteorites preserved in museums usually have a flat face worked upon them, which has been polished and then etched with acid, according to the technique usually practised in metallurgical research. The etching reveals a very remarkable structure, coarse enough to be examined without the magnification usually necessary for industrial metals. This etching process gives much information about the crystalline character of the specimen, and the pattern usually prevails without change of orientation over the whole surface, even in the largest meteorite. That is the ground for saying that only one crystal is concerned. In many cases the mutual inclination of the bright bands revealed by the etching process indicates that they mark the traces of the octahedral planes of the crystal. The fact that they show up at all proves that the material is not homogeneous, and in fact the bright bands consist of an alloy called taenite, which is considerably richer in nickel than the material of the broader and darker bands, called kamacite (figure 4).

The way in which this structure—called the Widmanstätten structure—has originated presents problems of considerable interest. If the nickel–iron is heated to, say, 1,000° C and re-examined afterwards, the structure is found to have disappeared, and so far no one has succeeded in reproducing it on anything like the original scale. To do so would involve a migration of metal atoms along distances of one or two millimetres through the metal, with a certain crystallographic rearrangement, into the details of which we do not here enter, all this occurring at a moderate temperature. Such a process might be expected to be extremely slow. Attempts to reproduce the structure by slow cooling have been made, and

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have produced something very like it on a microscopic scale. Not all metallurgists are convinced, however, that this is really the same thing, involving migration of the nickel. The present writer is hardly qualified to express an opinion on this point. Metallurgical laboratories are for the most part occupied with urgent commercial problems, and cannot afford to spend much effort on matters of purely scientific bearing; but undoubtedly there are interesting questions here awaiting solution.

Stony meteorites present some peculiarities not met with in terrestrial materials, but upon the whole these peculiarities are not very striking. Such meteorites are generally speaking of the same nature as ultrabasic terrestrial rocks, that is to say those terrestrial rocks which contain the minimum proportion of silica and the maximum of metallic oxides. Meteorites never show anything like the composition of granite, which contains so much silica that part of it segregates as quartz. No quartz is found in the stony meteorites. They approximate rather to those heavy terrestrial rocks called peridotites, which consist mostly of olivine, and which are probably much more abundant at great depths than they are at the earth's surface. However, the stony meteorites often show other features, rather suggesting the aggregation of angular fragments, and they also contain spherical bodies called chondrules, of sizes varying over a wide range—from a millimetre up to two or three centimetres. The smaller ones are more usual. The chondrules sometimes seem to be rather loosely enclosed, and can be picked out just as the currants can be picked out of a bun. There is nothing like them in terrestrial rocks, and it has often been thought that their more or less spherical form was probably produced by attrition; but under what circumstances is purely a matter of guesswork. The chondrules sometimes contain glassy matter, suggesting that they have been rapidly cooled. Their composition is not materially different from that of the meteorite generally.

Although we have dwelt on the iron and stony types of meteorite as representative, yet probably no meteorite is entirely free from metallic iron, nor are the irons altogether free from stony inclusions. The rather rare intermediate type of meteorite, in which iron and stone are present in about equal amounts, has always seemed to me to be specially interesting and intriguing. It is not closely comparable with any known terrestrial material, and to conceive the way in which it has originated presents obvious difficulties. These difficulties I believe to a great extent admit of solution, and we will now consider their problem at some length.

As we have seen, the stony meteorites, in spite of minor differences, are on the whole of the nature of igneous rocks of the ultrabasic kind. The iron meteorites are compact, and consist in most cases of one huge crystal. Moreover, the metallographic structure is of a kind which suggests secular cooling from a high temperature. We can therefore hardly escape from the conclusion that these materials have at one time been melted and have cooled very slowly. This is one of many reasons which indicate that the meteorites we examine have at one time formed part of a body of large dimensions, though as to the circumstances under which they became detached evidence is almost entirely lacking.

However, to return to the stone–iron meteorites. The most conspicuous and typical of these are called pallasites, after the eighteenth-century traveller Pallas, whose name is associated with a typical example. These consist of fragments of olivine contained in a network or sponge of nickel–iron. Sometimes the olivine fragments are single crystals so perfect in the symmetry of their development that they seem to have been grown under ideal conditions—as a crystal of alum may be grown in the laboratory, hanging from a thread and surrounded on all sides by the mother liquor, though with this difference, that the olivine crystals have the faces somewhat rounded. If we could suppose that melted nickel–iron could dissolve a siliceous material like olivine in the way that water dissolves alum, the appearance could be largely accounted for. But needless to say we cannot assume anything of the sort, and to me at least it appears that there are insuperable difficulties in supposing that the nickel–iron and the olivine have separated from an originally homogeneous liquid.

Moreover, the olivine in many other pallasites is of quite a different aspect. Instead of consisting of perfect individual crystals, it is in broken fragments. This is illustrated by the Imilac meteorite, of which a large mass can be seen—or rather could be seen in happier times—in the Natural History Museum (figure 3). In other cases again the olivine consists of rounded fragments, as in the Brenham pallasite (figure 5). Some authors have taken the view that these rounded fragments owe their shape to surface tension of the melted material. If drops of oil are suspended in dilute

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FIGURE 1 (*above*) – *Meteor crater, Arizona, 4,150 ft. wide, 600 ft. deep.*

FIGURE 2 (*below*) – *Comparative photographs of the moon (region near Aristarchus) by R. W. Wood. (Left): yellow light; (right): ultra-violet light. The dark patch is probably due to sulphur.*

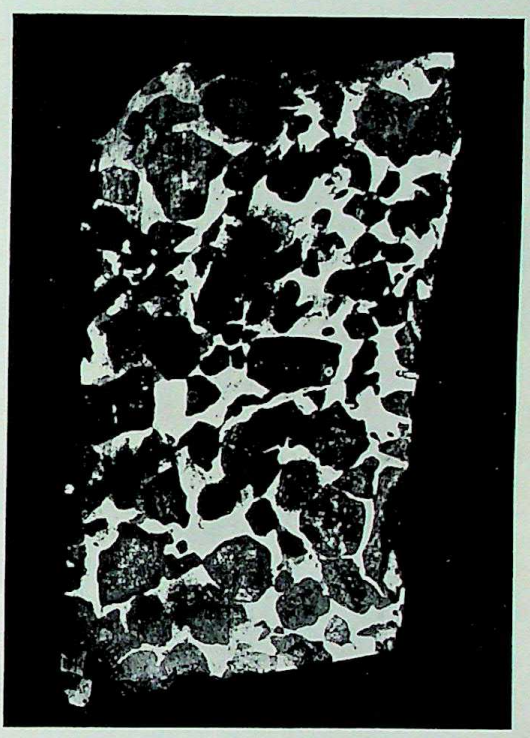
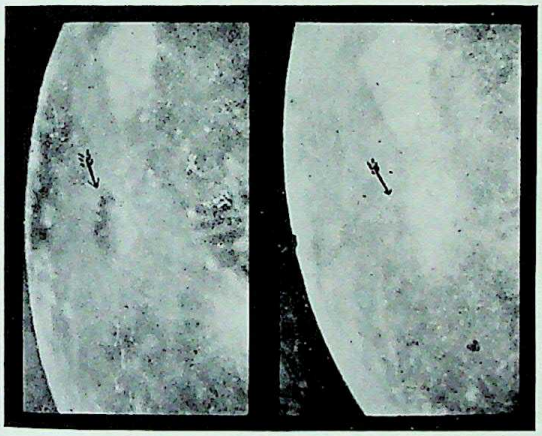


FIGURE 3 (*right*) – *Imilac pallasite, from a specimen in the possession of the author. Metal shows bright, olivine dark.*



alcohol of exactly the same density, they take a perfect spherical form, under the influence of surface tension, since this shape gives the surface of separation a smaller area than any other shape could do. The same cause makes a soap bubble spherical. It is true that the olivine is by no means of the same density as nickel–iron, but this difficulty must be faced in any case, for why did not the olivine all float up to the top? We shall return to this point presently. In the meantime the idea that the rounded shape is in any way due to drops is open to the objection that according to it the form ought always to be rounded, whereas in fact it is often conspicuously angular (see figure 3).

We find, in short, that some pallasites have more or less rounded olivine crystals, others rounded fragments without conspicuous crystal faces, and others again have conspicuously fragmental outlines. No theory which represents the olivine as having taken shape *in situ* in the iron mass can well cover all these cases, and for this and other reasons I prefer the view that they have taken shape quite independently, and have become immersed in the melted metal afterwards. Well-known natural processes will account for each of these shapes, the olivine crystals having been weathered out of a rock, the angular fragments produced by fracture, and the rounded ones by attrition. I thought at first that if the iron were melted the olivine would necessarily be melted also, and would form a layer on the top; but this is a mistake. The careful measurements

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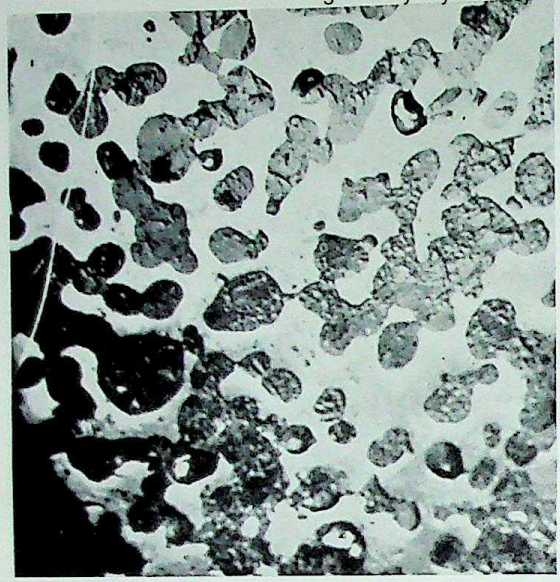

FIGURE 5 – *Brenham pallasite, from a specimen in the British Museum.*

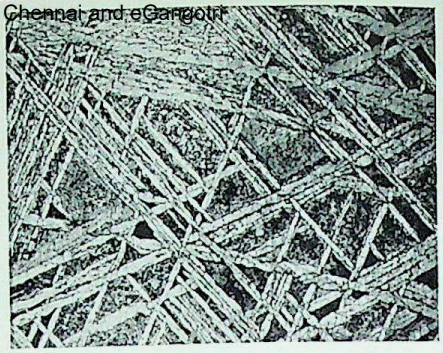

FIGURE 4 – *Widmanstätten structure: meteoric iron of Gibeon shower.* (*After Dr L. J. Spencer, F.R.S.*)

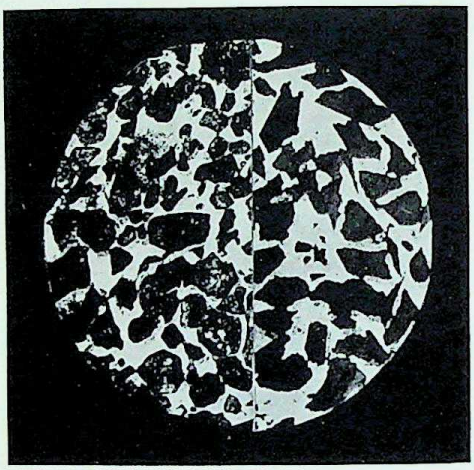

FIGURE 6 – (*left*): *Imilac meteorite;* (*right*): *synthetic imitation.*

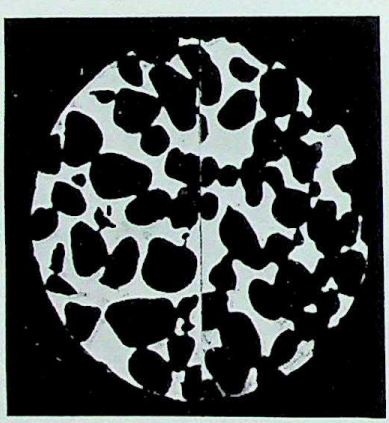

FIGURE 7 – (*left*): *Springwater pallasite;* (*right*): *synthetic imitation.*

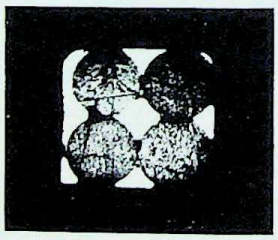

FIGURE 8 – *Steatite spheres immersed in solder and sectioned.*

of Bowen and Schairer have shown that the melting-point of olivine is nearer that of platinum than that of iron. There is no reason why a stratum of olivine fragments should not be engulfed by molten nickel-iron flowing in from below or from above, provided that the olivine were not free to float up. The necessary constraint to prevent this can be provided by the weight of material above lying on it.

This simple theory of the origin of pallasites has been tried out in experiment—not indeed by using iron and olivine, because these would require facilities for melting iron and for slicing the hard product which were not available. Resort was had to more tractable materials—steatite (soapstone) to represent the olivine and plumber's solder for the iron. The steatite fragments must be shaped according to the kind of pallasite we wish to imitate. They may be obtained by pounding up the material; or alternatively they may be rounded into pebbles by rolling them over and over in contact with one another, or

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(in order to get on more quickly) with hard objects such as hexagon steel nuts. It is then only necessary to sift the fragments free from powder and fill them into a mould. The melted solder is poured in, and after cooling the mass is cut up into slices, so that the structure can be conveniently examined. It is found to be closely representative of the structure of the pallasites. Figure 6 represents a synthetic product of this kind in comparison with the Imilac meteorite. Figure 7 similarly compares a synthetic product made from rounded fragments with the Springwater pallasite. The reader will perhaps agree that a good artificial imitation has been secured.

Melted metals—e.g. mercury—do not in general wet stone surfaces, and in consequence the melted metal will not close into the space between two pebbles right up to the point of contact. This is shown in figure 8, which represents the section of four steatite spheres placed in contact, with solder poured round. The necks apparently separating the spheres are characterised by *absence* of metal. The same thing is seen in those pallasites which contain rounded olivines (see figures 5 and 7) as in the synthetic reproduction, and is thought to confirm the view here taken as to their mode of origin.

In this article it has only been possible to touch lightly on certain aspects of a subject which has very wide ramifications. In particular, the important subjects of the age of meteorites and their astronomical relations have been left untouched. It is hoped that the reader's interest may have been sufficiently aroused to lead him to study the original literature.

In conclusion, a topic of considerable interest in connection with meteorites may be mentioned. At various times within the recollection of the present writer, there have been important developments on the subject of silica glass. These began with the work of Sir C. V. Boys (1855–1944) as long ago as 1887. Boys was interested in the production of fibres which would serve for the torsion balance—fibres which would have the desirable property that the restoring torque called into play by a twist would not vary with time, but would always be proportional to the twist applied. The glass or silk fibres commonly employed in laboratories before Boys' time were far from this ideal, and he conceived the idea of melting various minerals in the oxygen blowpipe and drawing them out finely, to see whether they would yield fibres mechanically better than glass or silk. As is well known, the production of quartz fibres was the result. But when the way had thus been opened, it was natural to go further. Fused silica prepared for drawing quartz fibres was found to have remarkable qualities in another way—that is in its small thermal expansion, which makes it much less liable to crack by sudden or unequal heating than vitreous substances in general. A considerable industry has been developed as the result of this observation, and large vessels of fused sand or fused rock crystal are produced commercially and are important in the chemical and electrical industries, for example in making the containing vessels for the valves used in wireless transmission. Here, however, we are not primarily interested in these industrial developments, but in the unassisted operation of Nature. Lumps of fused silica have been found on the sandy surface of the Libyan desert, and so far no satisfactory explanation of their origin has been forthcoming. They have been presumably lying there on the sand for long periods—long, that is, as judged by historical rather than by geological standards. In former times the waterless regions in which the silica is found were practically inaccessible, but the motor-car has changed all that, and the locality has now become comparatively easy of access, apart from the difficulties incidental to war conditions. Dr Spencer has taken a special interest in the subject, and has visited the spot. I am indebted to him for some specimens.

The question now presses for answer: How did these specimens of silica glass come to be deposited on the sandy surface of the desert? It must be confessed that no clear and satisfying answer to this question can as yet be given. There is nothing to suggest that the locality where the silica glass is found has been the scene of any violent convulsion of Nature. There is no sign of igneous action of any kind. The lumps of silica, sometimes clear, sometimes translucent, lie on the desert sand, and there is no vestige of an explanation of how they came there. The area of desert over which they are scattered is much too large to allow us to connect them in any way with the activities of man, and indeed the character of the material itself is such as to make it certain that no explanation is to be found in this direction.

Since there is nothing in the local geology to afford the slightest hint as to how the silica glass came there, and since the material itself may be regarded as unique and unlike anything known to exist elsewhere on the earth's surface, some have thought that the easiest escape from the

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difficulty is to assume that the silica glass fell from the sky. This hypothesis certainly cannot be disproved in the present state of knowledge. The appearance of the silica glass when it is actually found on the desert sand is admittedly difficult to explain on any alternative view. On the other hand, its chemical and mineralogical characters are very different indeed from those of recognized meteorites. We can but record the facts, acknowledging that they are difficult to fit into the framework of existing knowledge, and that they do not afford obvious clues for further research.

Museums

In a recent report[1] published by the British Association for the Advancement of Science, Dr A. S. Wittlin discusses the part of the museum in modern society. It is pointed out that the potentialities of the museum as an aid in education are considerable but have as yet hardly been tapped. Broadly speaking, the chief functions of the museum may be described as (i) the advancement of knowledge, or research, and (ii) the diffusion of knowledge, or education. Museums for the advancement of knowledge are collections forming parts of research institutions, and Dr Wittlin believes that fundamentally these are on the right lines. Museums for the diffusion of knowledge represent the majority of the museums of Europe, and on the whole must be regarded as badly lagging in development if compared with other institutions of modern society. This would seem to be due to the museum's insufficient contact with reality.

Among specific shortcomings of the average museum, Dr Wittlin lists incoherence of exhibits (a single room in one museum contained specimens representing sixteen different areas, six main periods of history, and more than twenty different subject-matters), monotony in selection and presentation of objects, overcrowding, architectural unsuitability, and lack of clarity in labelling. Many of these faults may be ascribed to the direct descent of the public museum from the private collection of the sixteenth to eighteenth centuries, but other factors, such as isolation and poverty, are partly responsible. In an additional note, Professor Sir John Myres remarks that every museum needs, for wholesome and efficient development, to be brought into direct and active relation with other scientific and cultural institutions of its locality—especially the libraries, which have the same double function of repository and illustration. Such close relation could be effected by representation on the museum's board of management, by arrangements for loans and exhibitions, and by provision of demonstrations or lecture courses at the museum. Active use of the collections in this and similar ways would bring deficiencies to the notice of those able to remedy them, and would call public attention to the museum's needs as a public and social institution. Further financial aid is necessary. The present standard of provision is too low, partly because the museum has been too often regarded as a storehouse for unwanted objects rather than as an aid to study.

For future development a prime requisite is the training of museum curators. Up to the present, no standards exist for the professional qualifications of curators, and Dr Wittlin suggests that the universities should take this matter in hand. He recommends a one-year post-graduate course, with a syllabus including such subjects as the history of civilization and of arts and crafts, the theory of education, the principles of psychology, and museum architecture, crafts, chemistry, and administration. Abbreviated courses might usefully be arranged for teachers and other educationalists wishing to use the museum as a method of teaching.

With trained curators available, the reorientation of museum policy could be systematically undertaken. Numerous technical problems await solution, but these are less important than the formulation of a definite programme of general aims. Man's consciousness of human capacities and of aspects of human society may be considered as a major requirement in present-day education, and the museum might clearly do as much in this direction as in the more traditional path of surveying material culture and the world of nature.

While the report thus sees much that is unsatisfactory in the present state of museums and museum policy, it notes that efforts have been, and are being, made to improve the situation.

[1] *Advanc. Sci.*, 1944, 3, 9.

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The Royal Institution of Great Britain

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THOMAS MARTIN

The Royal Institution of Great Britain, founded nearly 150 years ago by Benjamin Thompson, Count Rumford, has performed yeoman service to the cause of science and still happily continues its flourishing existence. Mr Thomas Martin, who has been General Secretary of the Institution for many years, provides a bird's-eye view of its history and points out that it has now become a centre of international scientific co-operation.

At the end of the eighteenth century one of the intellectual centres of London was the house in Soho Square of Sir Joseph Banks, the gouty and autocratic President of the Royal Society. No scientific enterprise could hope for success without the President's approval; and when Count Rumford launched his proposals for a new institution 'to facilitate the introduction of useful mechanical inventions' and to 'teach the application of science to the common purposes of life,' the first meeting was naturally held at Soho Square under Banks's chairmanship. The plan was adopted, and the Royal Institution of Great Britain was founded on 7th March, 1799.

FIGURE 1 – *Michael Faraday.*

Benjamin Thompson, Count Rumford, an American who had fought on the British side in the War of Independence, had recently returned to London after service as a high officer of state under the Elector of Bavaria. In Munich he had made his well-known experiments on the heat generated by friction in the boring of cannon, and had established a reputation for practical philanthropy and the administration of establishments for the poor. Pursuing his philanthropic interests in London, his new Institution was designed to introduce the benefits of science to the working people; while at the same time the higher ranks of society, to whom he looked for financial support, were to share the advantages by means of scientific lectures and experiments.

A house in Albemarle Street was taken, Rumford personally supervising every detail of the arrangements. He designed the famous lecture theatre himself. He drew up the constitution of the new body with its hereditary Proprietors and Committees of Managers and Visitors. He engaged professors—Thomas Young, of the wave theory of light, was one of the first. But his greatest contribution to the success of the Institution was made when he engaged a certain young Cornishman, Humphry Davy—who had become known for experiments on nitrous oxide—as lecturer in chemistry.

Davy's success was immediate. He had natural gifts of exposition, and all London flocked to Albemarle Street to hear him lecture. The new laboratories gave him opportunities for experiment, and before long he was launched on the career of discovery which made him the greatest chemist of his age. The chemical action of the electric current, the discovery of new elements (particularly sodium and potassium), the proof of the elementary nature of chlorine, and the invention of the miner's safety lamp are among the researches that brought fame to him and to the Institution in which he worked. He was knighted by the Prince Regent, was elected President of the Royal Society, and became the acknowledged leader of English science.

Humphry Davy established the great tradition of research and exposition which has ever since characterized the Royal Institution; but in doing so he altered the institution Rumford had planned. The school for mechanics, the exhibition of model stoves and appliances, and the demonstrations of cookery were dropped. The changes were recognized by Act of Parliament in 1810, which incidentally dispossessed the hereditary Proprietors

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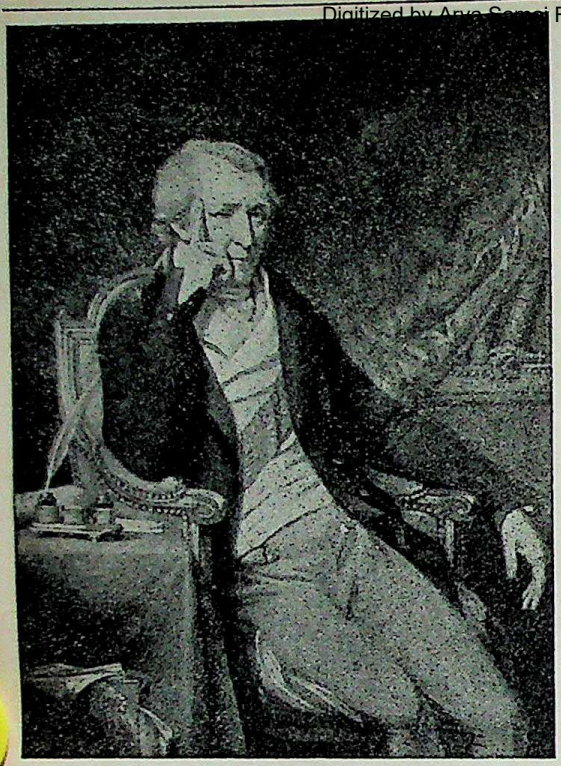

FIGURE 2 – *Benjamin Thompson, Count Rumford.*

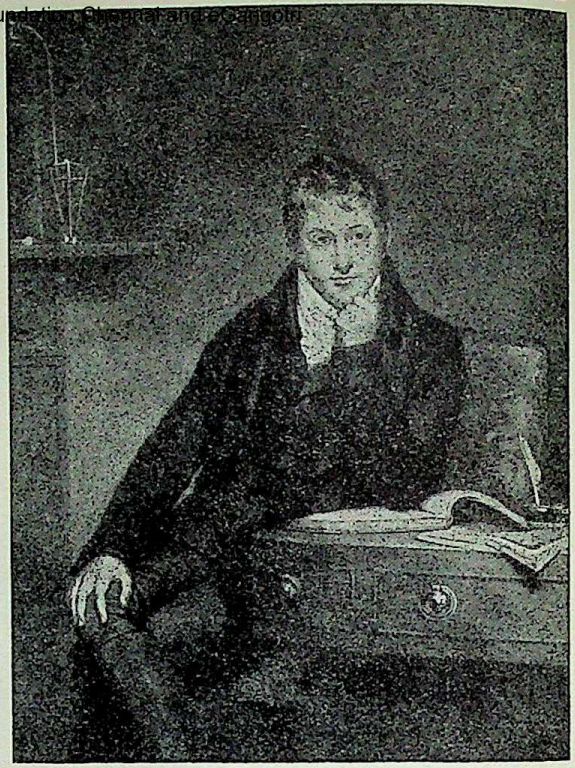

FIGURE 3 – *Humphry Davy.*

and substituted for them a body of Members.

In 1813 Davy had engaged as assistant in the laboratory a young man, formerly a bookbinder's apprentice and the son of a blacksmith. The assistant was destined to succeed his master, and to rival or exceed him in scientific fame, for the blacksmith's son was none other than Michael Faraday. Soon he was appointed Superintendent of the House, and brought his young wife to live at the Institution; and when John Fuller endowed his professorships, Faraday became the first Fullerian Professor of Chemistry.

Faraday maintained and extended the tradition Davy had established. As an experimental lecturer he was without a rival, and those well-known features of the Institution's work, the Friday Evening Discourses and the Christmas Juvenile Lectures, owe their inception to him. The fame of his researches has become almost legendary. First a chemist, he discovered benzene, the foundation of the dye industry, and worked on alloy steels and optical glass. He liquefied chlorine. Turning his attention to electricity, the long series of experimental researches followed which have become the foundation of modern electrical science. The greatest of his discoveries, that of electro-magnetic induction, is the origin of the dynamo and the beginning of the generation and distribution of electric power in the service of man. Faraday's life and work have remained the spirit and inspiration of the institution he loved.

A succession of great men has followed Faraday. John Tyndall, lecturer, writer, experimenter, and mountaineer, succeeded him as Resident Professor. James Dewar's Friday Evening Lectures on liquid air are still remembered. In the laboratories Dewar first liquefied hydrogen. He invented the 'Thermos' or Dewar flask; and with his liquefied gases experimented at extremely low temperatures and originated the modern technique of refrigeration. Lord Rayleigh extracted argon from the gases of the atmosphere. In more recent years Sir William Bragg and those who worked with him have developed the new science of analysis of crystalline structure by means of X-rays.

Generations of men of science have found in the Royal Institution a source of encouragement and inspiration. In recent years it has been a centre of international co-operation and accord among scientific men—as at the Faraday celebrations in 1931. When war is ended and frontiers are opened again, the Institution will be ready to resume its functions and help in its own sphere to restore peace and friendship among the nations.

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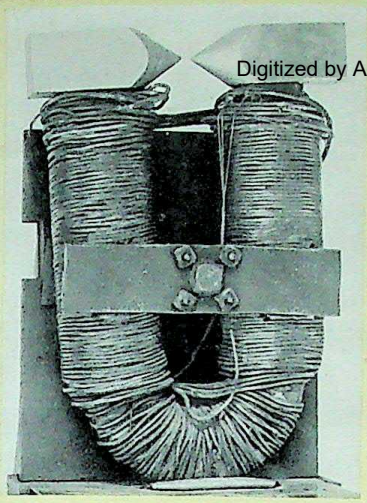

FIGURE 4 – *Faraday's great electromagnet.*

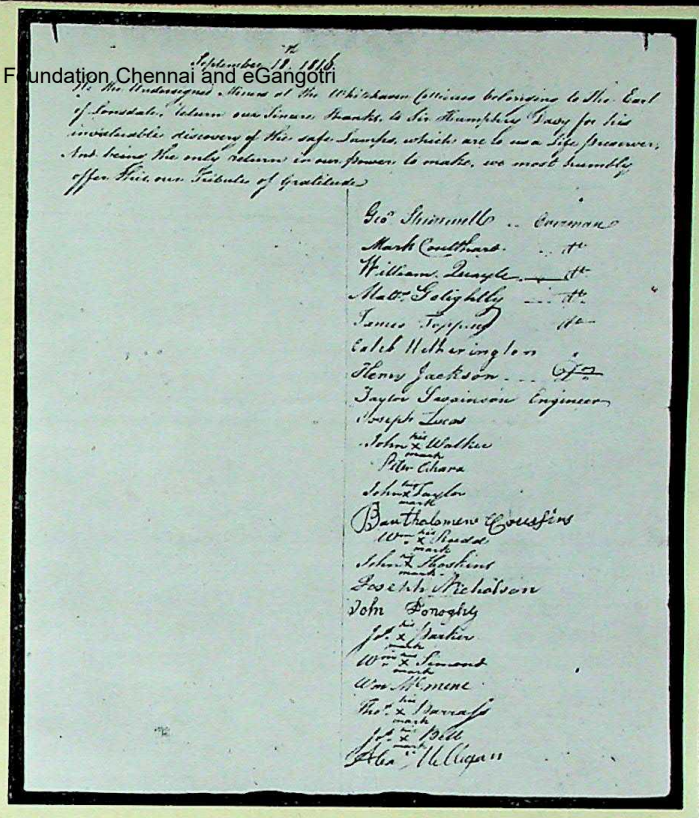

FIGURE 5 – *Miner's safety lamp. Letter conveying the thanks of the Whitehaven colliers to Davy.*

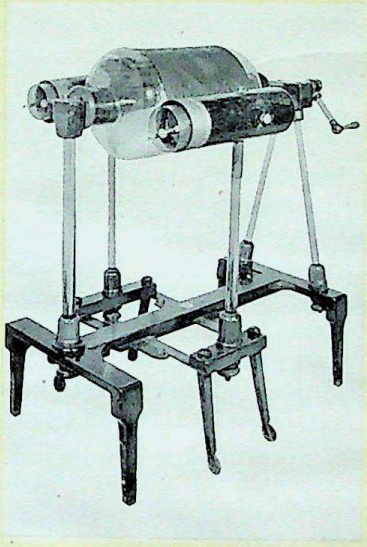

FIGURE 6 – *An early electrical machine by Nairne used at the Royal Institution.*

FIGURE 7 – *Miner's safety lamp. Experimental lamps used by Davy.*

FIGURE 8 – *Faraday's specific inductive capacity apparatus.*

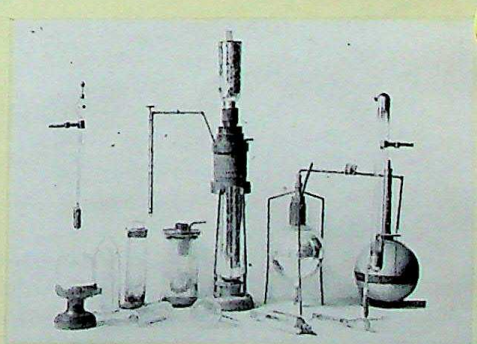

FIGURE 9 – *Dewar vacuum vessels.*

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Mercer and mercerization

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A. W. BALDWIN

Mercerization, like silhouette, has become so familiar a word that its derivation from a patronymic is apt to be overlooked; but John Mercer was as real as Etienne de Silhouette. A Lancashire man with a passion for chemistry, he thoroughly deserved the title of 'Father of Textile Chemistry.' His discoveries laid the foundation for the manufacture of highly lustred, or 'mercerized,' cotton; for the invention of viscose rayon; and for a process of making cuprammonium rayon.

A hundred years ago, in a village in Lancashire, England, a calico printer named John Mercer treated cotton with caustic soda and noted that its properties had been profoundly changed. This was the first step in a process for the transformation of cotton, a process which was to become known throughout the world as mercerization, and was perhaps the most important observation made in a lifetime devoted to pioneer investigation in the field of textile chemistry.

John Mercer was born in 1791 at Dean, in the parish of Great Harwood, near Blackburn, where his forbears had lived for several generations. In 1800 the early death of his father left his mother and her three children almost destitute, and young John, at the age of 9, commenced work as a bobbin-winder. It was during this period that he made his first contact with the Oakenshaw Print Works, which was to be associated with most of the discoveries he made throughout his life. An employee of this calico-printing firm, a pattern designer named Blenkinsop, took the trouble in his spare time to teach a very earnest and obviously able child the first principles of reading, writing, and arithmetic. This was the only schooling or training of any kind bestowed upon one who was to become ultimately a Fellow of the Royal Society, a reader of papers to the British Association, and an associate of the nineteenth-century giants of British scientific philosophy. The seeds of Blenkinsop's teaching fell upon most fertile soil, however, for it soon became apparent to the more intellectual of the local worthies that the boy Mercer had a most remarkable flair for learning, and particularly for mathematics.

Mercer's first introduction to the art of dyeing was in 1807 when, as a youth of 16, he visited his mother, who had married again. He was so fascinated by the bright orange colour of a frock worn by a child step-brother that he became obsessed with a determination to learn dyeing. He proceeded by the only possible route for one in his position. He sought and found the druggist in Blackburn who supplied the local dyers, and bought small samples of everything needed for dyeing—brazilwood, logwood, quercitron, alum, copperas, etc.—to the tune of a total expenditure of half a crown. He took his purchases home and began to experiment.

His experiments were so successful that he set up in a small way as a dyer, in partnership with a friend, and in less than a year was acquiring a local reputation. He was soon persuaded, however, by Mr. Fort of the Oakenshaw Print Works, to give this up and to apprentice himself to the older and established firm. The opportunity to extend his knowledge more rapidly, aided by professional guidance, was too good to miss, but unfortunately the new job did not work out quite as he had hoped. About this time the Oakenshaw Print Works entered a period of hard times brought on by the Berlin Decrees[1], and when they offered to release apprentices from their obligations Mercer, who had been constantly frustrated by a foreman who frankly considered him an upstart and an aimless meddler, took the opportunity to leave. He returned for a livelihood to hand-loom weaving, a craft he had learned as a boy.

A few years later, as was inevitable with such a man, he resumed his amateur dabbling in dyeing, an appropriate prelude to a chance event which was to influence the whole of his life. Whilst browsing in a second-hand bookshop in Blackburn, actually a few days before he married, he picked up a copy of *The Chemical Pocket Book*, by James Parkinson of Hoxton. This revealed an entirely new and fascinating world to him, a

[1]The Berlin Decrees were Napoleonic edicts which ordered, *inter alia*, the confiscation of all British merchandise on the continent of Europe.

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FIGURE 1 – JOHN MERCER, F.R.S.
1791–1866

world which he quickly realized to be of prime importance to the dyer and printer. No sooner had he begun to study, or rather devour, this book than he started to experiment on the basis of his reading, for that was always Mercer's way. Phenomena recorded in a book had to be witnessed on the bench; any theory which occurred to him promptly became the subject of laboratory trials by whatever means he could devise. His initial study of Parkinson bore early fruit, and he was soon able to develop novel printing effects by the application of simple inorganic chemistry. Hearing of these discoveries, Mr. Fort asked him to rejoin the Oakenshaw Print Works, but this time as a chemist—at a salary of thirty shillings a week!

This fresh start, which was undertaken without any reproaches for the shabby treatment he had received earlier, was the real outset of Mercer's career. Eagerly seizing the more adequate

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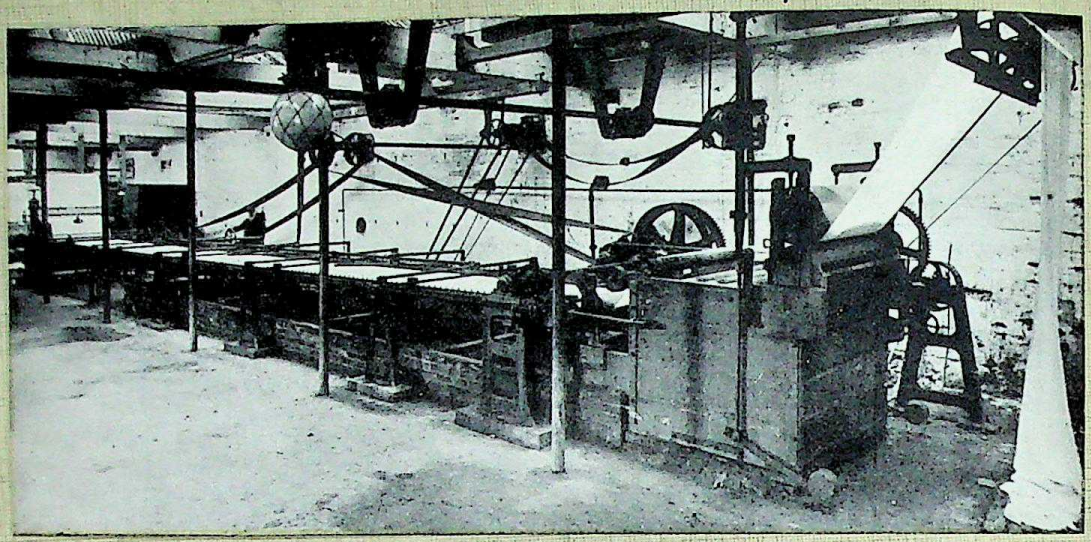

FIGURE 2 – *One of the first complete machines for mercerizing cloth continuously in the piece. Installed about* 1898. *Photograph taken from the delivery end.*

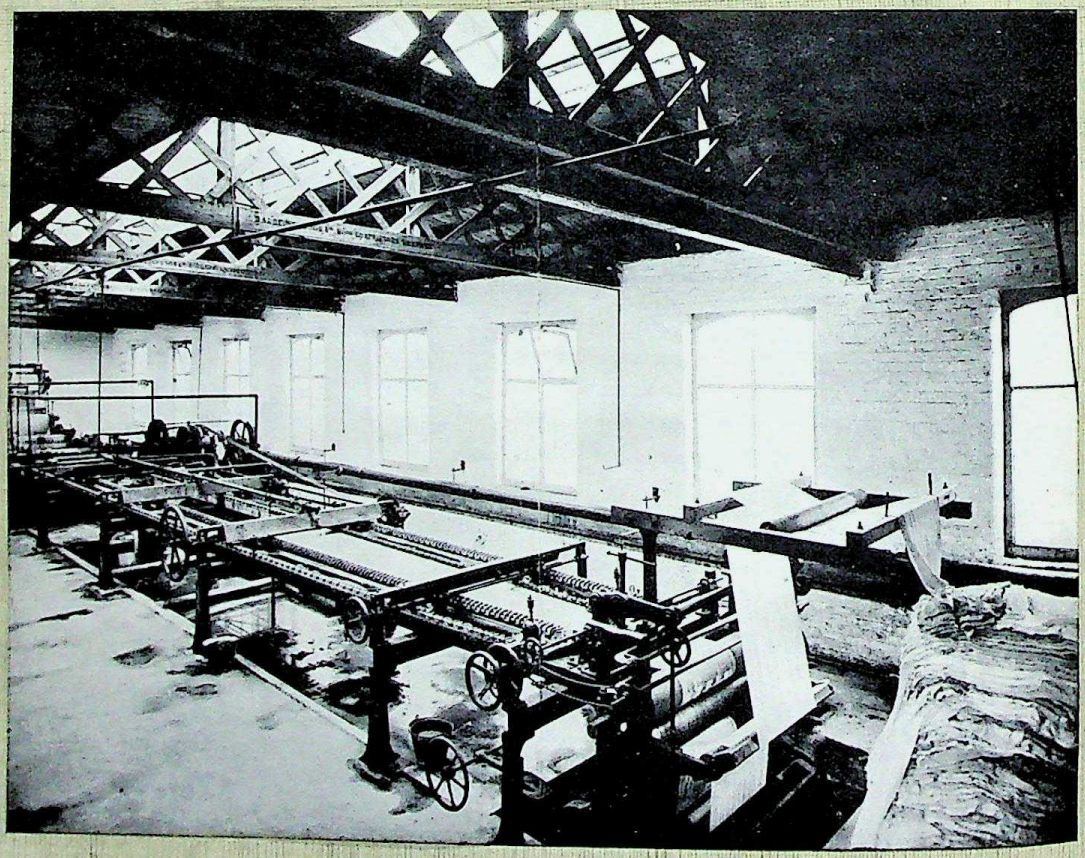

FIGURE 3 – *Another early machine, installed about* 1900. *Photograph taken from the entering end.*

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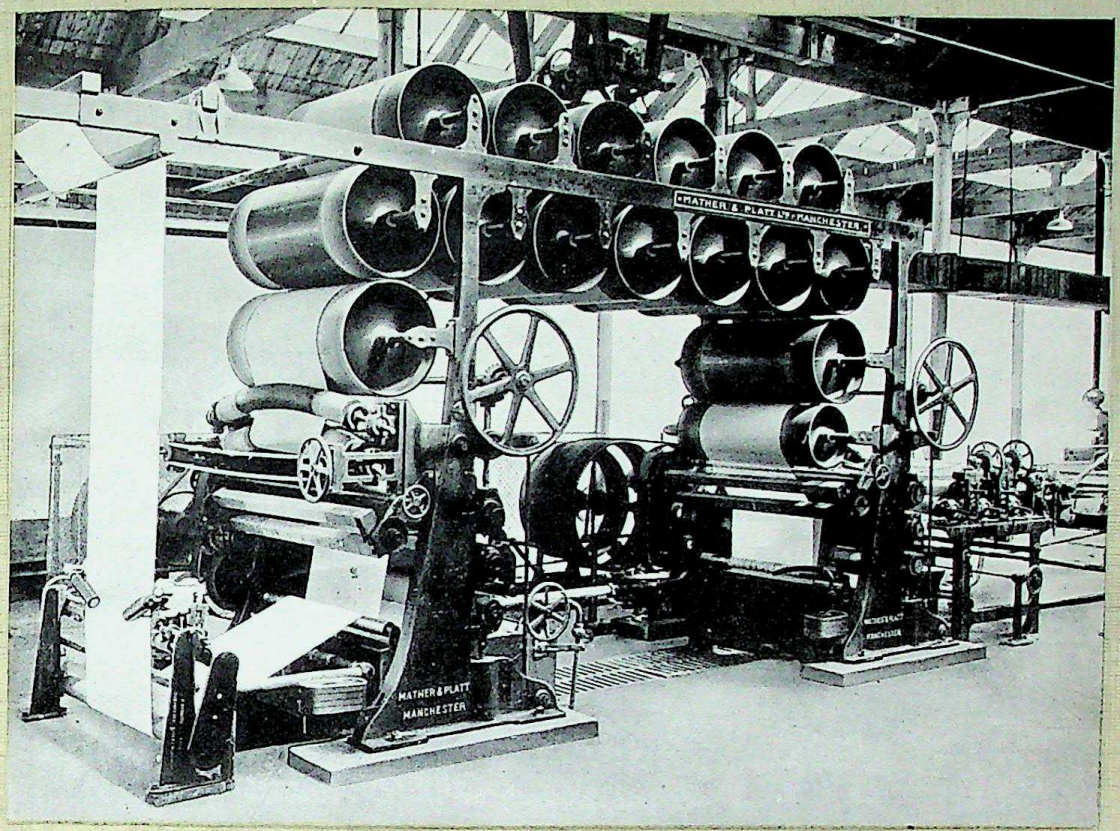

FIGURE 4 – *This is one of the most recent and up-to-date mercerizing ranges installed in England, showing the two three-bowl impregnating mangles with intermediate sheet-iron drums for impregnating the cloth with caustic soda before stretching on the stenter.*

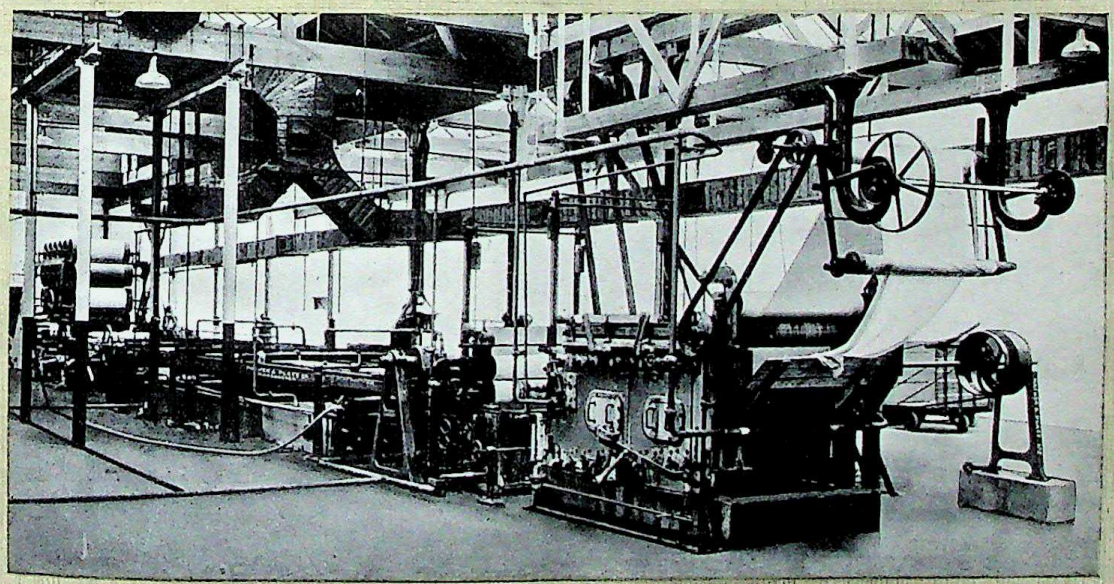

FIGURE 5 – *Another view of the same machine taken from the delivery end.*

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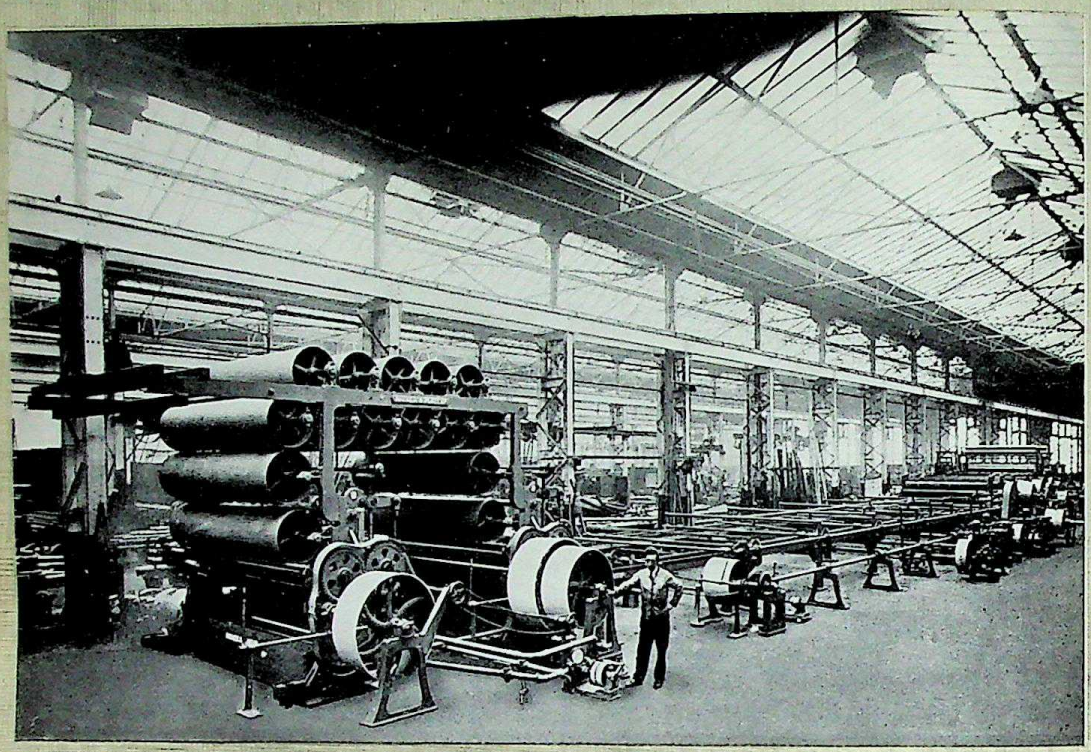

FIGURE 6 – *This is a mercerizing range for cloth* 100 *in. wide, and is probably the largest and most powerful machine of its kind in the world.*

(The photographs of mercerizing ranges by courtesy of Mather and Platt Limited)

laboratory facilities available to him, he embarked upon investigations which were to leave their mark on the trades of dyeing, printing, and finishing textiles. There is little doubt that any chemist of average competence would have effected profound changes in these trades, for in the eighteen-forties they were ripe for the introduction of chemical method as a change from guesswork. Mercer was on the spot, however, employed in the very heart of the industry instead of in a university laboratory. It thus fell to him to show the benefits immediately to be gathered by the purification of raw materials, by analysis, leading to correct measurement, by control of temperature, and, consequently, by general standardization of operations. In seven years he had set his firm on the high road to prosperity, and at the end of this period he was rewarded by being taken into partnership.

Mercer was indeed entering upon his most

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fruitful period, and further than merely standardizing dyeing processes. Apart from having a methodical and tidy mind, he had an extremely lively imagination and was a most prolific inventor. Here, however, it becomes necessary to divide his achievements into two broad classes: those which immediately concerned dyeing and calico printing and which rapidly found expression in the sales of his company, and those which called for development in wider fields where, unhappily, pioneers of similar calibre were not available or, at least, were not in touch with Mercer's work. On the one hand, the production of new yellow print effects by the precipitation of antimony sulphide on the fabric, the discovery of a new method of fixing Prussian Blue, and the substitution of a phosphate together with a glutinous material, carrageen, for the old-established dunging process, were promptly applied industrially, as this lay in his own hands. Similar success awaited many other technical devices, too numerous to mention here. A case in point, however, arose in the printing of delaines. To get the wool to print as readily as the cotton, Mercer chlorinated it. The effect on the printing world of this entirely novel operation was commercially gratifying, but there was nobody at hand to follow up the work, by investigating other effects of the process, and it was not until sixty years later that the non-shrinking properties of such chlorinated wool were realized. Again, as part of a method for improving the printing of Turkey Red he evolved a new product by the sulphonation of olive oil, but the wider application of this reaction, which pointed the way to the manufacture of Turkey Red Oil and the modern detergents and wetting agents, was not investigated until considerably later.

The most noteworthy example of such delay, however, was in the work mentioned at the beginning of this paper. In 1844 Mercer was carrying out research which had been inspired by certain experiments of Graham's; he was particularly interested in the formation of hydrates in solution. With a view to measuring viscosity and mobility of solutions, he passed caustic liquor through cotton linters. The interesting results which he observed in preliminary fashion had to be set aside, owing to the pressure of the firm's business and, later, to a severe illness. On his return to work, however, he took up the study of this 'fulled cotton' at the first opportunity. He found that he had increased the tensile strength of the cotton, increased its weight by about 5 per cent., and imparted to it a much higher affinity for dyestuffs. When he applied the caustic soda to cotton in printing styles he got an interesting crêpe finish and a further novel effect by after-dyeing. Shortly after this work he found that he could swell cotton by treating it with sulphuric acid and zinc chloride solutions, and observed, as also did Schweizer independently, that cellulose could be dissolved in a solution of copper oxide in ammonia. All these observations had been made by 1850, and were fully recorded, but very little came of them for over forty years. The main reaction from a conservative cotton trade was that Mercer had succeeded in shrinking cotton, an undesirable effect for which there was no market. Yet he had laid the foundation for the highly lustred cotton, now known as mercerized cotton, produced in 1890 by Lowe, who carried out the caustic treatment under conditions that prevented shrinking and thereby set up lustre; for the invention of the viscose rayon process by Cross, Bevan, and Beadle in 1892; and for the Bemberg process of manufacturing cuprammonium rayon. The more modern plastics industry, requiring a variety of cellulose derivatives which need to be prepared from soda cellulose or alkali-activated cellulose, owes a great deal to these early investigations.

Mercer always displayed a deep interest in theoretical chemistry. He formed a discussion group at Whalley, a nearby village, where he propounded his views on catalysis, the phenomena of chemical combination, affinity, and many other topics; and he was in frequent correspondence with Graham, Playfair, and other great chemists in Britain. Throughout all, however, he remained primarily a bench worker, quick to test theory by experiment, to tackle problems resolutely as he met them, and to follow them up as far as he could, no matter where they led him. Observations of the photochemical reactions of certain inorganic salts led him to devise novel photographic printing processes on paper and on cambric in a variety of colours; these he described in a paper to the British Association at Leeds in 1858 and exhibited to the Photographic Society of Vienna. Following an investigation of a complaint from a South American customer concerning the mildewing of some printed calicoes, a problem to which he found a technical solution, he went on to speculate about moulds and bacteriological growth. This latter was characteristic of the lively interest Mercer displayed,

(*Continued on page* 149)

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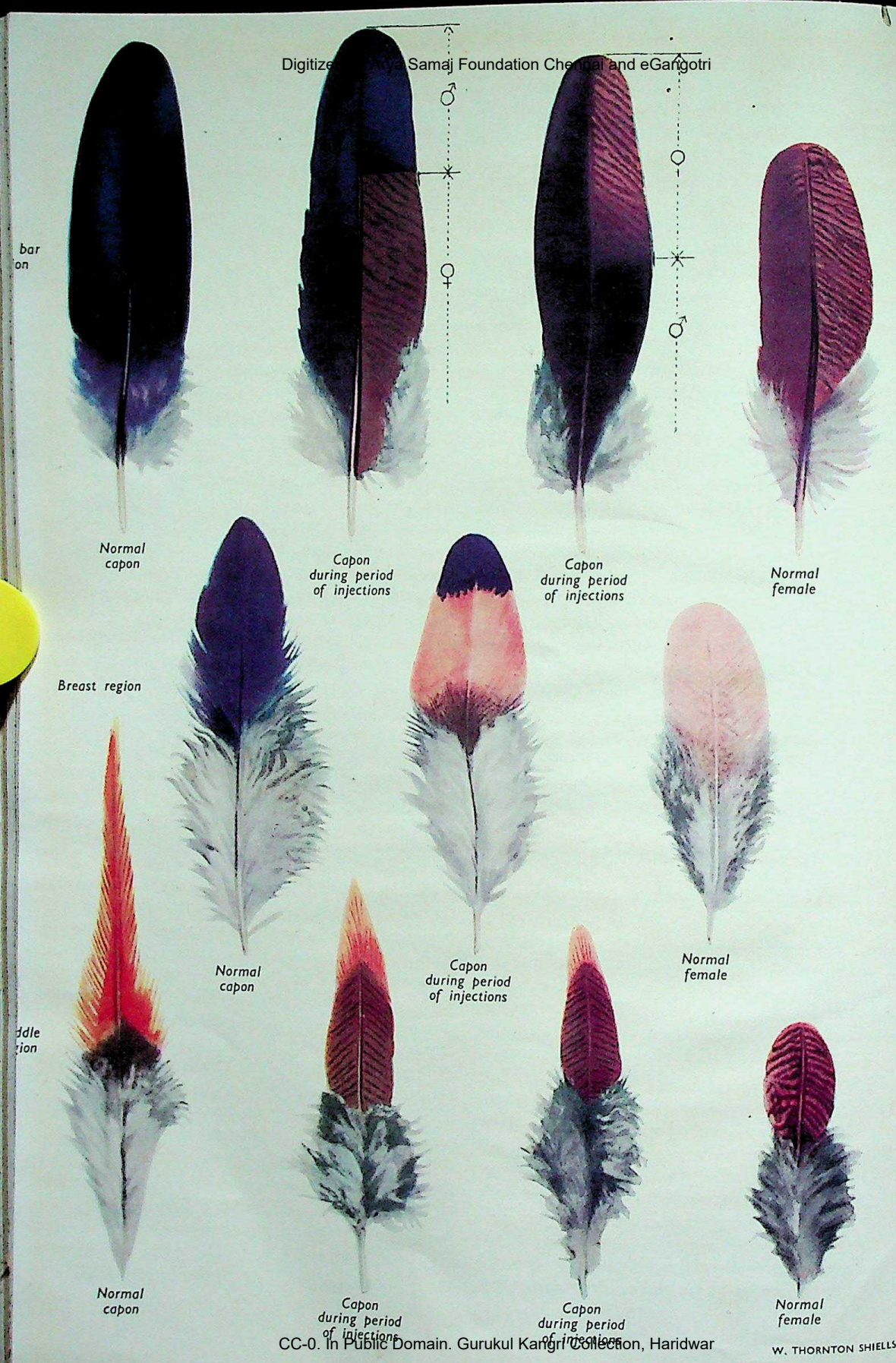

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W. THORNTON SHIELLS

Synthetic oestrogens

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E. C. DODDS

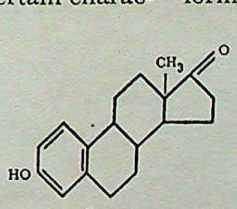
Substances secreted by the ovaries control the female sexual cycle. They are known as oestrogens, and their chemical constitution has been elucidated. Within the last few years substances more powerful than the natural oestrogenic bodies have been synthesized, and have been used clinically with remarkable results: e.g. in the relief of symptoms associated with the climacteric and the termination of lactation in women, and in the treatment of cancer of the prostate. They form a group of potent drugs of great interest and promise.

It is unusual for investigations which at first sight appear to be solely academic to produce important practical results in a relatively short time. That this has been the case with synthetic oestrogens will become apparent as the present article develops. Only recently quite unexpected uses of these substances have been brought to light, particularly in the treatment and control of one form of cancer. It will be necessary to give a very brief review of the naturally occurring oestrogens before we can enter into a consideration of the artificial or synthetic substances.

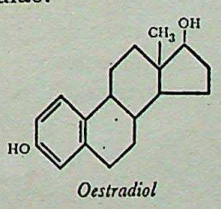
That the female sexual cycle and functions were associated with the ovary has been known from time immemorial; and since the development of the idea of internal secretions towards the end of the last century it has been recognized that the ovaries act by producing a substance which, entering the blood-stream, reaches the reproductive tissues and produces the characteristic cyclical changes of the adult female. It was only natural that organic and bio-chemists should try to isolate this active principle from the ovary. Years of careful work were handicapped by lack of a suitable quantitative biological test. This was introduced in the 1920s by Stockard and Papanicolou.

Working with small rodents such as rats and mice, they showed that there were certain characteristic alterations in the cells of the reproductive tract at a certain stage of their sexual cycle, and that this could be demonstrated in smears of the reproductive passage. If the ovaries were removed the alteration in the cells ceased, but could be restarted by the injection of an active substance into the castrated rodent. This fundamental observation was made by Allen and Doisy. Extensive chemical work was undertaken, but little progress was made other than to say that the substance was of a fatty type, soluble in organic solvents and containing only carbon, hydrogen, and oxygen. As extracted from the ovary, however, it was found to be unpurifiable by the methods then available, and the best preparation consisted of a sticky oil of unknown constitution. The turning-point came in 1927, when Aschheim and Zondek made the truly remarkable observation that the urine of pregnant women and animals contained very large amounts of this female sex hormone or oestrogen. Moreover, it was shown that the substance present in the urine, when obtained by extraction with volatile solvents such as benzene or chloroform, was in a much purer state than that obtained from the ovary. This discovery gave an entirely new impetus to the whole subject. In a relatively short time a number of chemists and bio-chemists (Marrian in England, Doisy in the United States, and Butenandt in Germany) had obtained crystalline products, and by a series of intensive chemical investigations in various parts of Europe and America the constitution of the oestrogenic substance was elucidated.

It was found that there were three main oestrogenic substances—oestrone, oestradiol, and oestriol; their structure is shown by the following formulae:



Oestrone



Oestradiol

Oestriol

This was fully established by 1932 and is the starting-point of the investigations forming the main part of this article. The substances all have the same basic skeleton, but differ in the distribution of

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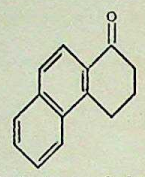
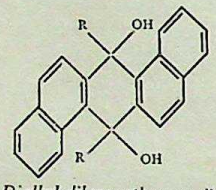
their hydroxyl and ketone groups. Together with Cook and Hewitt, the writer decided to investigate how specific were the demands of the body for an oestrogenic substance, seeing that at least three were produced in nature. Very numerous derivatives of phenanthrene were prepared as a start and were tested on ovariectomized rats. It was quickly shown that the substance 1–keto–1 : 2 : 3 : 4–tetrahydrophenanthrene produced



1–keto–1 : 2 : 3 : 4 :–tetrahydrophenanthrene

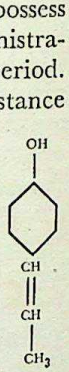
the same qualitative results as did the injection of any of the three naturally occurring substances. There was, however, a great quantitative difference. Whereas as little as one to two thousandths of a milligram of oestrone was required to produce changes in a rat, as much as 100 mg. of the simple phenanthrene derivative was necessary for the same purpose. A series of other compounds was obtained by the same workers, and one of the dialkyldibenzanthracene diols, whose general formula is shown below, was found



Dialkyl-dibenzanthracene diols

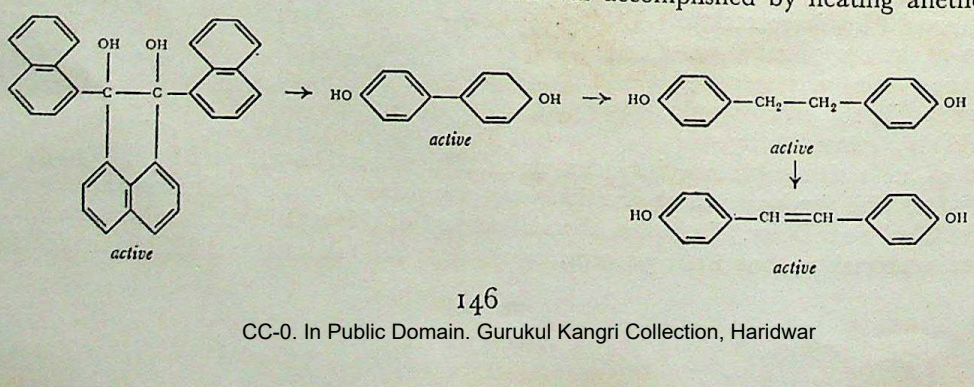
to be very highly active—although this was definitely the exception. The work, however, looked encouraging when it was shown that all the effects of the naturally occurring hormones could be reproduced. As an example the writer, together with Greenwood, showed that when injected into capons these compounds were capable of producing the same characteristic feminizing effect on the plumage as do the natural oestrogens. This is well indicated in the coloured reproduction (p. 144). On the left of the illustration are feathers of the normal capon, which are masculine. On the extreme right are feathers of the normal female, and in the middle are seen feathers modified by an injection of synthetic oestrogens. It is at once apparent that the injection produces an immediate feminization of the feather, which reverts to its male character after the injection has been terminated. Up to this point all the compounds possessed the phenanthrene ring system, and the next step was to determine whether this structure was essential for oestrogenic action.

The writer, together with Lawson, investigated the activity of a number of compounds in which only two rings were fused, and obtained positive results with some of these. Still further simplification of the molecule necessary for oestrogenic action was attempted. The series of formulae at the foot of the page shows the various stages through which the investigation proceeded. It can be seen that we finished up in this series with the second relatively simple substance 4 : 4′–dihydroxystilbene or dihydroxydiphenylethylene. The parent hydrocarbon stilbene or diphenylethylene possesses activity, and this series has been developed by Robson and his co-workers. These substances are of much lower activity than those about to be described, but some of the earlier ones possess remarkable properties in that a single administration is capable of acting over a very long period. It must again be emphasized that this substance possessed only a fraction of the quantitative activity of the naturally occurring hormones.



Anol

An attempt was made to simplify the molecule still further by dropping off, so to speak, one of the benzene rings of 4 : 4′–dihydroxystilbene and substituting a methyl group for it. This substance, anol, was obtained by demethylation of anethole, a naturally occurring product which is the methyl ether of the substance required. This reaction was accomplished by heating anethole with



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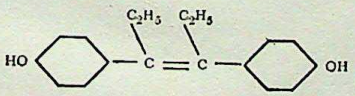
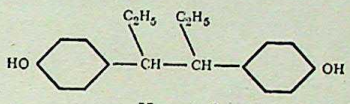
alkali and alcohol under high pressure in an autoclave. The resulting phenol was separated and crystallized, and was found on injection into ovariectomized rats to possess a very high degree of activity. Attempts to repeat this observation, however, showed an alarming discrepancy in the activity between the various batches of anol, and it became obvious that a serious error had crept into the work. Several anol batches were compared and their activity was found to vary from that of a very high order down to practical inactivity. A study of the chemical properties of anol revealed that it very rapidly polymerized, and we came to the conclusion that the activity was probably represented by a polymer formed during the demethylation of the original anethole. This view was supported by the observation that the mother liquor from which the phenol was crystallized always contained a high degree of activity. When concentrated, the mother liquor yielded a glassy mass which had a fairly high oestrogenic activity, but out of which in the first instance it appeared impossible to obtain a pure crystalline compound. A review of the situation led us to believe that the activity was a polymeride of anol and that on theoretical grounds it was likely to be a dimeride. The obvious next step, therefore, was to synthesize every possible dimeride of anol. On general principles it might be guessed that the active one would be the symmetrical dimeride. In the meantime, an investigation had been begun at Oxford by Sir Robert Robinson to prepare possible oestrogenic agents bearing a close structural resemblance to oestradiol, and it was decided to join forces. The synthesis of the symmetrical dimeride 4 : 4′-dihydroxydiethylstilbene was eventually accomplished, and this substance was found to be of astonishing potency. It has the following formula:



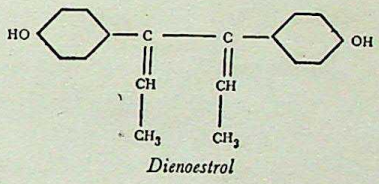
Stilboestrol

Its quantitative activity as compared with oestrone showed that it was roughly two and a half times as powerful; it could therefore have been a possible contaminant of the original anol. The development of this substance, which we eventually termed 'diethylstilboestrol' and which is now known as 'stilboestrol,' was a great practical step forward, but it was felt that stilboestrol was not sufficiently active to explain the potency of certain samples of anol. A determined attempt was made, therefore, to separate the contaminating substance from the mother liquor of the anol crystallization, and with the collaboration of Campbell this was eventually accomplished. The compound was shown to be closely related to stilboestrol and to differ from it only in the fact that the double bond between the α and β carbon atoms was hydrogenated. The same substance can also be prepared by the catalytic hydrogenation of stilboestrol. It was finally called 'hexoestrol' and has the following formula:



Hexoestrol

A further variant was obtained by an entirely different synthetic route, and this possessed double bonds in the side-chains attached to the central carbon atoms; it was known as the hexadiene compound and later as 'dienoestrol.'



Dienoestrol

We have therefore three substances—stilboestrol, hexoestrol, and dienoestrol—all more powerful quantitatively than the naturally occurring hormone, yet bearing only a superficial resemblance to it in structure. These substances present fascinating problems from every point of view. First, from the stereochemical aspect there are two possible stilboestrols—the *cis* and the *trans* forms. These have been isolated, and we know that the more active compound, and the one at present used in clinical medicine, is the *trans* variety. In the case of hexoestrol we know that the substance used in clinical work is the *meso* or internally compensated compound, hexoestrol having two asymmetric carbon atoms. The isomers of dienoestrol have not yet been fully investigated.

From the biological point of view the interest in these substances is obviously very great. They can replace in every way the naturally occurring substances, and as already pointed out their resemblance from the structural point of view is only very slight. It is possible to write the formula of the *trans*-stilboestrol in such a way that it does apparently bear a relationship to the naturally

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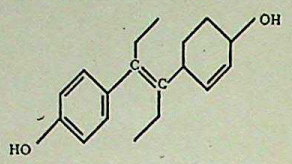
occurring oestradiol, as shown in the following diagram. It is difficult to express the activity of



the three principal synthetic oestrogens in terms of oestrone and oestradiol, but in a general way it may be said to be between two to five times as active. The great difference between the synthetic substances and the natural hormones is that whilst the latter are practically inactive when given by mouth, except in very large doses, the three synthetic substances are highly active when so administered; dienoestrol is probably the most active. Again, these synthetic substances are very cheap to produce and have given the experimental biologist and clinician an entirely new weapon for research. During the last six years many hundreds of papers have appeared in British and overseas journals as to their pharmacological and biological effects, and it would not be possible to review here all the various uses to which they have been put. To the clinician they are of the utmost interest since they present an inexpensive method of supplying the body with oestrogens; they therefore find employment in all cases where the naturally occurring hormones were previously employed. They have two outstanding advantages as compared with the natural hormones in that (i) they cost very little indeed; (ii) they can be given by mouth. The clinical employment of the naturally occurring hormones necessitated either subcutaneous or intramuscular injection, thus limiting their use to persons who could employ a doctor or alternatively attend at a clinic. Today, synthetic hormones are given in very large quantities to out-patients of hospitals.

The clinical application of the substances is extremely wide. It will perhaps be sufficient to give two of the main uses. Perhaps the most outstanding value is in the treatment of the distressing symptoms associated with the change of life in women. There now exists a large body of literature to show that in practically all cases this trying and difficult period can be completely relieved by the daily administration of a few milligrams of this substance in the form of pills. The vasomotor symptoms such as hot flushes, and the unfortunate mental instability which is associated with this period, and which causes so much human suffering, can be completely abolished in practically all cases.

The second great use is in the termination of lactation on weaning a breast-fed baby. This period is again known to be one of the most trying from the patient's point of view, attended as it is with acute pain and anxiety, and in some cases with actual infection requiring surgical intervention. The administration by mouth of an adequate quantity of the synthetic oestrogen terminates the secretion of milk abruptly and without any secondary effects.

In a certain percentage of cases slight nausea and side reactions are experienced in the early stages of the administration of synthetic oestrogens. This is said to be most noticeable with stilboestrol and least with dienoestrol, hexoestrol occupying an intermediate position. These symptoms, however, are really insufficiently serious to preclude the use of the compounds, and in most cases are entirely absent. It may be noted that the nausea is of central origin and probably has the same origin as the vomiting and nausea of pregnancy, as it is during early pregnancy that the body is flooded suddenly with an excess of oestrogen.

In addition to these two main indications, the synthetic oestrogens have also been used in other conditions in which the naturally occurring hormones have been insufficient, and they therefore play an important part in many types of gynaecological therapy.

At the beginning of this article attention was called to the fact that rarely does an academic investigation lead to immediate practical results. The foregoing paragraphs have shown that the synthetic oestrogens are exceptions. An entirely unforeseen and particularly fortunate use for these compounds has emerged from recent work. One form of cancer can now be controlled and the patient rendered symptom-free for periods as long as the treatment has been available—namely some three to four years. Cancer of the prostate gland is perhaps one of the most terrible forms of this disease. In addition to the usual ghastly progress, such as the formation of secondary deposits with pressure on nerves and intractable pain, this particular form of cancer is associated in its quite early stages with obstruction of the urinary outflow and all the horrors and suffering associated with it. The Chicago surgeon Huggins, for reasons which it is not possible to describe here, decided that if the activity of the testes could be overcome by castration or any other method, the relief of prostatic carcinoma symptoms might be obtained. It had been shown

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previously that large doses of oestrogens inhibited the anterior lobe of the pituitary and that this produced a castration effect. After a long series of experiments, he eventually tried the effect of stilboestrol given by mouth. The effects were very encouraging and in many cases dramatic. We already have experience of numbers of patients treated in this country who have been rendered symptom-free, and maintained in a healthy condition whereby they can return to work. Not only are the local urinary disturbances completely relieved, but the extension of the secondary deposits appears to be inhibited and may even show some shrinkage; thus intractable pain due to pressure on nerves, and of a severity requiring morphia, has entirely disappeared. Even those cases showing pressure on the spinal cord have been completely relieved.

Whilst the results are unique in that it is the first occasion that any form of cancer has been controlled by a medicine administered by the oral route, it is only natural that the greatest caution should be observed in the interpretation of these results. The length of time that the treatment has been available is too short for us to say whether the relief can be maintained indefinitely, and under no circumstances can the treatment be regarded as a cure. That it is most encouraging, however, there can be no doubt.

With further experimentation, it may be that the synthetic oestrogens will find extending fields of usefulness; but even if they do not proceed any further, they certainly form a particularly interesting group of new, highly potent drugs, with much future promise.

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Mercer and mercerization

(*Continued from page 143*)

over a period of years, in medicine and in the medical application of chemistry. In the year 1848 his prompt and liberal application of bleaching powder was considered to have halted the spread of cholera in his district when four deaths occurred in a neighbouring village. While it cannot be said that he made any fundamentally important contributions to the knowledge of these several subjects, the examples quoted provide ample evidence of an extraordinary breadth of outlook.

By 1850 Mercer had achieved recognition, and indeed distinction, in academic circles. In 1852 he was elected to Fellowship of the Royal Society, but not without some persuasion—his natural modesty deterred him from joining such august company. He was elected a Juror in each of the two great International Exhibitions of 1851 and 1862. At the former, Queen Victoria was graciously pleased to accept a gift of cotton handkerchiefs which had been printed by Mercer's novel alkali process.

Mercer has been styled the 'Father of Textile Chemistry' and the 'Self-taught Chemical Philosopher,' but a truer picture would show him as a typical Lancashire man with a passion for chemistry. He died in 1866 in the surroundings in which he had lived, and was buried in the church of St. Bartholomew, Great Harwood, Lancashire.

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The trend of British veterinary parasitology

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E. L. TAYLOR

In Great Britain, the most economically important parasites of domestic animals are the helminths. British veterinary parasitology is therefore primarily concerned with helminthology, and Dr Taylor describes recent work in this field. When the rationale of anthelminthic action is better understood, it will be possible to apply chemotherapeutic methods to full advantage, and thus to establish a firmer control over the parasites than is as yet practicable. At present their eradication appears to be quite out of the question.

It is a surprising thought that most of the living things in the world are parasites; but it is even more surprising to learn that the *species* of parasites are also more numerous than the species of hosts on which they live. Many kinds of animals and plants have several parasite species peculiar to themselves, and most parasites are strictly limited to a small group of hosts, so that the complete field of operations open to the student of general parasitology is a very large one indeed.

Veterinary parasitology as a subdivision of this field might be thought to concern itself with all the parasites of domestic animals; and no doubt this was so while the knowledge available to the early naturalists remained within the compass of a single human brain. The piling up of information has necessitated a subdivision of the work, however, and a research department of veterinary parasitology, or a book on the subject, may now be expected to deal primarily with helminthology, probably also with protozoology, perhaps with entomology as well; it may even deal with mycology, but it will certainly not deal with either bacteriology or the study of viruses.

In all its branches the growth of parasitology has followed the same general lines: firstly, a study of the morphology of the parasites and their classification; secondly, a study of their life-histories; and thirdly, their association with disease. In so far as the parasites of veterinary interest are concerned, the most useful work of the morphologist and systematist is now complete, as is also the work on the outline of life-histories, which, with few exceptions, is adequate to explain the origin of infection.

This important preliminary work is, in some respects, outside the veterinarian's field of activities. It is more proper to the biological laboratory, concerning, as it does, the structure and ordinary life of creatures which only under exceptional conditions are responsible for disease. A conventional subdivision into 'normal parasitology' and 'pathological parasitology' is a good one. It helps to define the special province of the medical or veterinary investigator, whose main object, whatever means he may employ, is the understanding of disease.

By far the most economically important parasites in Great Britain are the helminths, and the story of parasitic disease in Britain largely centres round the derangement of the ecological balance between these parasites and their hosts. This derangement has been occasioned by various agricultural developments, chiefly concerning the improvement of pastures and the increased concentration of stock. Some half-dozen helminth species and closely related groups of species are principally concerned, and the three main lines of research are (1) a minute study of the bionomics of the parasite in its life outside the mammalian host, (2) a study of the mutual reactions of the mammalian host and its parasitic community, and (3) the investigation of the parasiticidal treatment of the affected host.

As yet, eradication of these parasites appears to be quite out of the question. They occur wherever our grazing animals are kept, and the only practical objective for our present endeavours to prevent disease must be the control of parasite multiplication and the maintenance of their numbers at the normal ecological level.

The study of the bionomics of the free-living larvae of the nematode parasites of grazing animals has done much to improve our understanding of the epidemiology of the diseases which they cause. These investigations are now being extended from the laboratory into the field, and more direct epidemiological studies are being

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made, with advantage, at the actual places where the diseases occur. Some interesting information, for instance, has recently resulted from a technique developed for the estimation of the numbers of infective nematode larvae in pasture herbage, and it has been surprising to find what large numbers are ingested daily by the grazing animal. A heavily infected sheep pasture, on which, however, the grazing lambs still show no outward sign of disease, may carry some 400 parasitic nematode larvae per pound of herbage; and as sheep, while grazing, eat some 15 to 20 lb. of herbage daily they must as the same time ingest about 8,000 young parasites. The percentage of the larvae which develops in young and susceptible lambs is high, and the parasites reach maturity in less than three weeks. Their potential life is relatively long, and as some 40,000 or 50,000 are sufficient to cause death, the importance of the resistance to parasitic invasion that develops in the grazing animal is clear.

The observations on the high rate of larval intake by animals at pasture also emphasize the benefit to be derived through the grazing of heavily infected herbage by an insusceptible kind of stock. The larval worms are too hardy to be injured by top-dressings of lime, salt, or other substances unless these are applied in large amounts, such as would at the same time destroy the grass. Ploughing does not dispose of them since they migrate to the surface again, so that alternate grazing by insusceptible stock appears to be the only quick way of reducing the infection of the field. Hence, hard grazing with sheep or cattle is of great benefit to horse pasture; the thousands or tens of thousands of larvae which are collected daily by each individual sheep or cow are destroyed, and the pasture is rendered relatively clean.

In addition to the grazing by stock of a species differing from that which had been responsible for the infection of the ground, adults of the same kind may similarly be used to clean the pasture for the younger animals, as their resistance is comparatively great, and the larvae which they ingest are destroyed.

The application of the technique for the recovery of larvae from pasture herbage shows the benefit that may also result from grazing adult and young animals together. It is found, for instance, that towards the end of the summer lambs which appear to be healthy may be passing as many as 9,000 eggs per gram of faeces. Supposing thay they void some 900 gm. of faeces daily, then the daily output of eggs will be some 8,000,000. The herbage where such lambs are grazing, however, is found to carry not more than 400 larvae per pound, so that lambs eating 20 lb. in a day will ingest some 8,000 larvae. It may be supposed, therefore, that to maintain a rate of intake of 8,000 larvae per day it is necessary to add to the pasture some 8,000,000 eggs daily, or one thousand times as many as the larvae that will become available. Ewes, however, at the same time of year, will be passing only some 900 eggs per gram of faeces, representing 800,000 eggs daily. This figure, at the same proportionate rate, would represent only 40 larvae per pound of herbage. Each ewe, therefore, if grazing on heavily infected pasture along with the lambs, would ingest and destroy some 8,000 larvae daily but would add only 800, so showing a balance to the credit side of 10 larval parasites destroyed for every one added to the pasture.

The grazing of adult stock along with the young is usually thought to be unsound on account of the danger of transmission of parasites from the resistant adult carriers to the susceptible young animals. The observations on larval intake show, however, that in heavily infected pasture at least, the presence of adult animals is a distinct advantage, and that intensive grazing with young animals alone must be regarded as a dangerous practice.

These few examples will be sufficient to show how the observations on the larvae as they exist in the actual pastures are helping to clear up the epidemiology of these group helminthic diseases, and indicate the best lines for the direction of our efforts at control. Another aspect of parasitism, and one which is of the greatest importance from the point of view of epidemiology, concerns the resistance of the host to invasion by the parasites. Until quite recently, parasites have been regarded as entering into a kind of struggle for existence with their hosts, the ultimate outcome of the struggle being either the destruction of the parasites on the one hand or the death of the host on the other. Such a view of the relationship is now recognized to be wrong, as it ignores the biological need of provision for the continuity of the parasite species. This continuity would be seriously threatened by any marked lethal action upon its host, an action that would lead in the end to the annihilation of the parasite as well. A mechanism has therefore been evolved for the maintenance of a balance, the two chief forces in this mechanism being the production of excessive

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progeny on the part of the parasite and the development of a resistance to excessive infestation on the part of the host. This resistance, which has been built up during the mutual evolutionary development of the host and the parasite species, must be of a very complex nature. It may reasonably be assumed, for instance, that the common nematode parasite *Strongylus vulgaris* has been associated with the horse since an early period; that *Eohippus*, the earliest recognized equine ancestor, carried some similarly primitive ancestor of *Strongylus vulgaris;* and that the two have evolved together into what they are seen to be today. Their present immunological relations may therefore be regarded as the outcome of the repeated development of 'attack' mechanisms on the one hand and 'defence' mechanisms on the other, and must now be of a very complicated nature and difficult for us to unravel.

The laboratory side of this study of parasitological immunity has received a considerable amount of attention during the past fifteen years. The mechanism, in general, conforms to that of bacteriological immunity, although the relatively large size of helminth parasites and their localized nature has led to certain differences in the approach to its investigation. There has been a tendency, for instance, to draw a distinction between resistance to the actual infestation itself and resistance to the effect of infestation, a distinction which could hardly be made for microscopic parasites, where 'effects' of parasitism are almost indispensable for the first recognition of its occurrence.

The most definite kind of immunity is that due to out-and-out incompatibility of host and parasite. Age immunity, of which there are one or two good examples in parasitology, may be regarded as of the same nature; but the branch of immunity which most concerns the veterinary parasitologist is that of resistance acquired as a result of previous infection. The greater part of the laboratory work on this acquired immunity has been done on hookworms in dogs, on stomach worms in sheep, and on a small nematode, *Nippostrongylus muris*, in rats. The immune response is found to develop very slowly, compared with the rapid rate of the development of acquired immunity to many bacterial infections. No doubt the very different rates of increase of the two kinds of parasites in the animal body have some connexion with this variation. Bacteria multiply rapidly in the host and so call forth a rapid response of the defence mechanisms, whereas the increase of parasitic helminths is, in comparison, a slow process, depending entirely upon the gradual acquisition by the host of eggs or larvae from the environment; there is therefore no necessity for a rapid response of the defence mechanisms.

One other manifestation of immunity to helminth parasites is that of 'premunition,' or the resistance of a host to further infection of a parasite that it is already carrying. This kind of resistance operates only so long as the infestation persists, and has been clearly demonstrated in the association of one or two cestode cysts with their hosts. It is not unlikely that premunition also plays its part in the protection of grazing animals against some of their nematode parasites, for small infestations of these worms are almost invariably carried, even by the most resistant adult hosts.

Because of the persistence of this residual infestation, and also, perhaps, on account of the slow rate of its development, there appears to be a tendency to regard helminthic immunity as a subject for academic study, without practical importance where disease among farm animals is concerned. This, however, is an erroneous conception, as becomes apparent when the epidemiological aspect of the resistance is considered. The food of grazing animals is subject to continuous contamination with their own faecal matter; the eggs of their parasites reach the pasture by the million per day from each moderately infested animal; the daily intake of infective larvae is a matter of thousands; and the grazing animals would be quite unable to survive the resulting heavy infestation were it not for the development of this powerful resistance. Acquired helminthological immunity is a very strong immunity. It is usually adequate for the complete protection of adult animals that may be grazing on pastures where young animals, not so protected, are dying of helminthiasis, and its place in the epidemiology of parasitic disease is of the greatest importance. It is not unlikely that a considerable part of the future endeavours of the veterinary parasitologist will be directly aimed at the investigation of methods by which this host resistance may be encouraged, and maintained at its maximum potency. Acquired immunity is the *natural* protection. In a state of nature it is adequate to protect the host in all but the most unusual stresses, and there is no doubt that under agricultural conditions its operation may be considerably assisted.

One of the directions in which these endeavours may be made is in the avoidance of conditions

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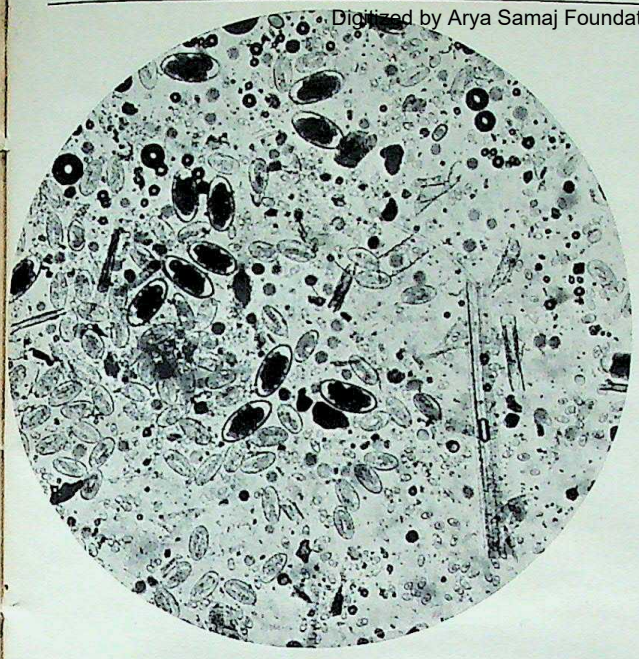

FIGURE 1 – *Concentration of strongyloid (nematode) eggs collected by salt flotation from the faeces of a healthy lamb carrying a normal infestation of the adult worms.*

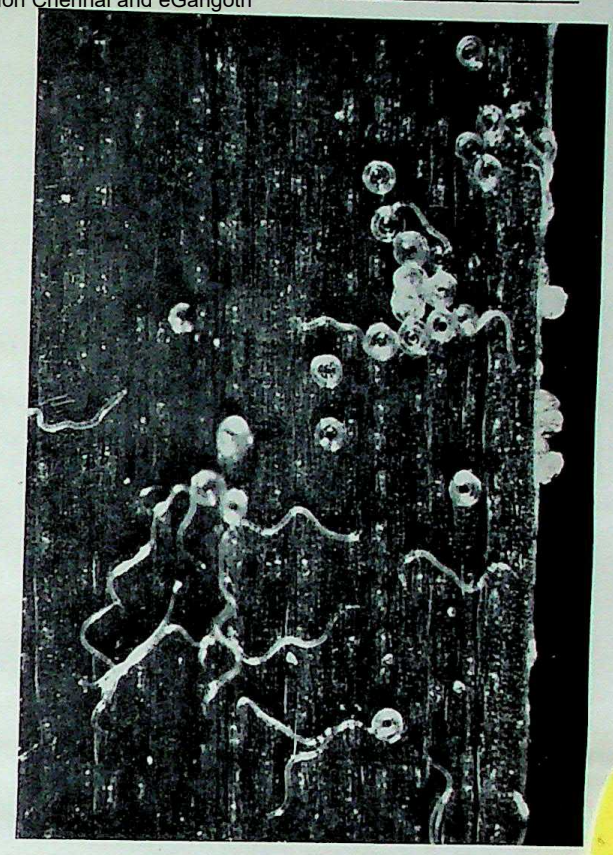

FIGURE 2 – *Infective strongyloid (nematode) larvae on a blade of grass.*

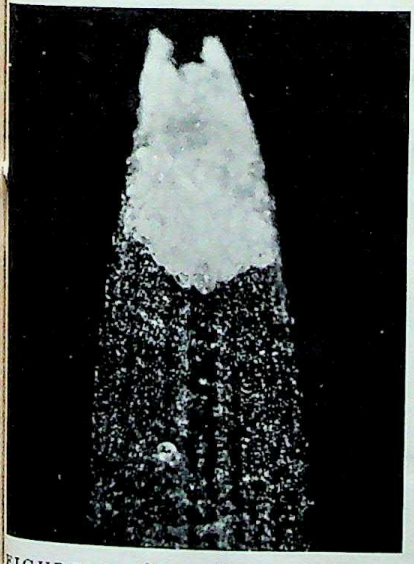

FIGURE 3 – *Mass of strongyloid larvae on the top of a heavily infected blade of grass. Specimens such as this may occasionally be found in the region of deposits of horse faeces.*

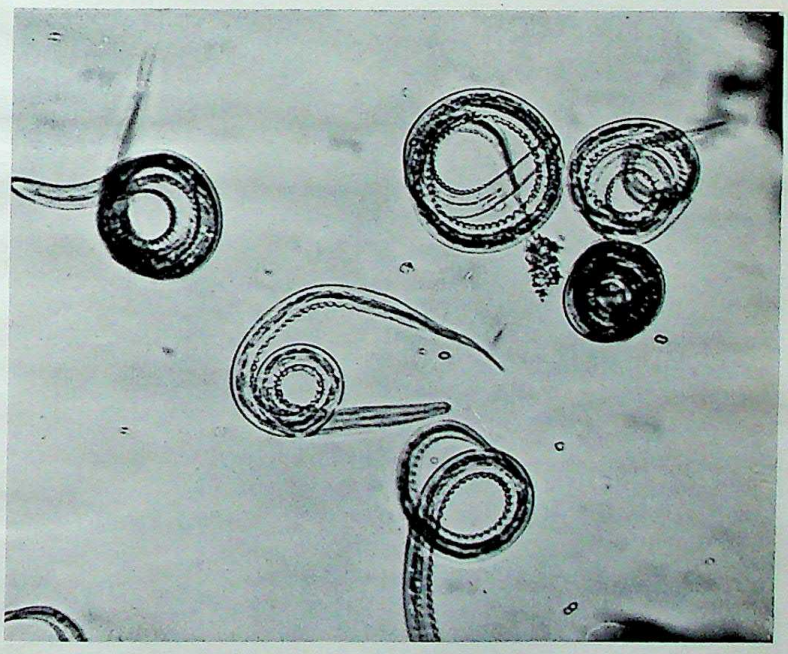

FIGURE 4 – *Infective strongyloid larvae showing the protective sheath (thrown into folds on the inner curvature), which renders them very resistant to adverse weather conditions.*

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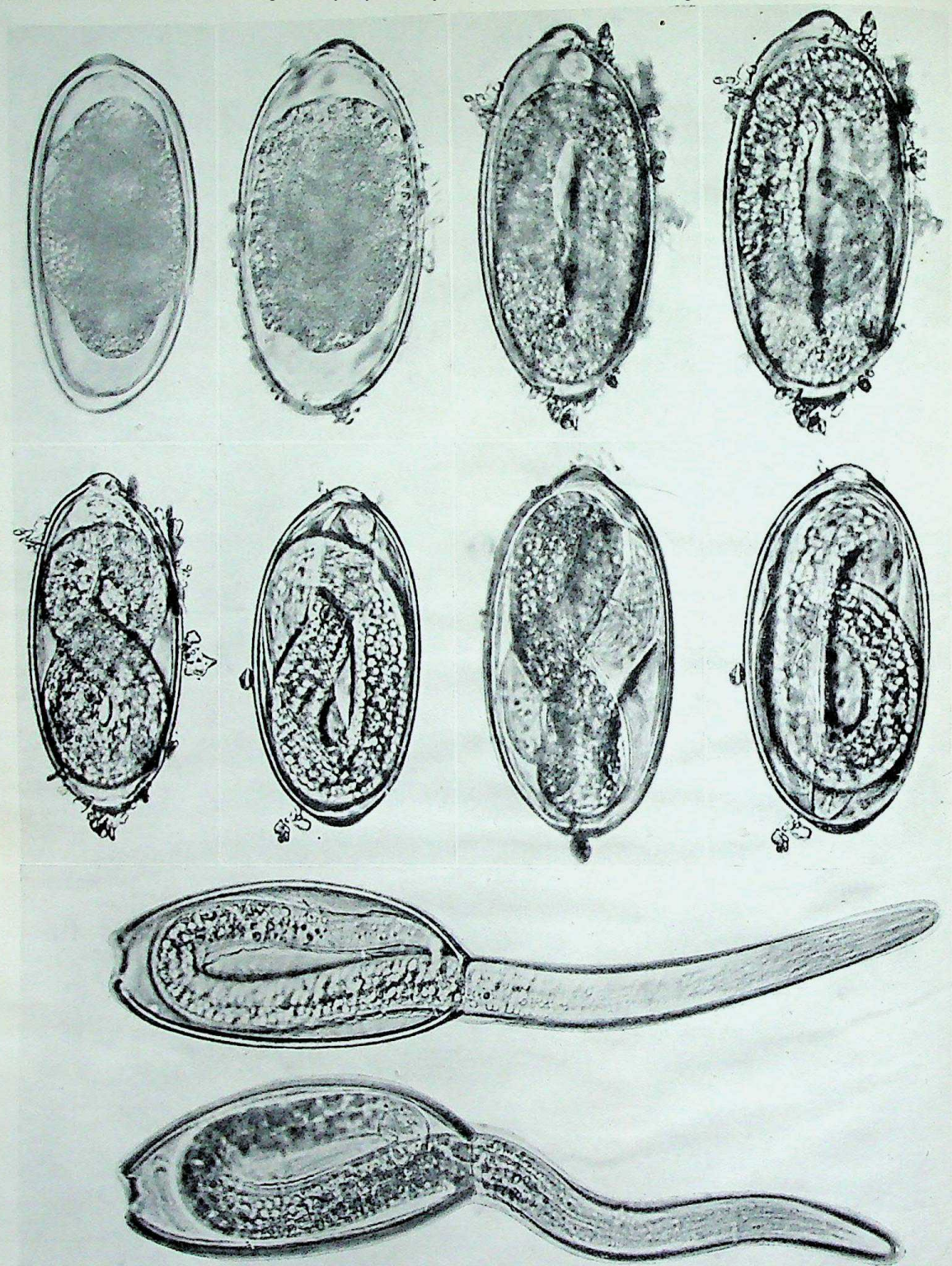

FIGURE 5 – *Development and hatching of the larvae of the strongyloid worm* Syntamus trachea *photographed on successive days. The eggs of most of the strongyloid worms of grazing animals reach the hatching stage within* 24 *hours.*

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that tend to delay the establishment of immunity or to break it down when once it has been formed. It has been shown under experimental conditions, for instance, that certain mineral deficiencies and vitamin deficiencies are able to do this, as may also a diet of a very poor general quality.

Medical investigations into the epidemiology of bacterial diseases have, however, led to the conclusion that diet is of secondary importance. Some investigations into helminthic disease appeared to confirm this, as it was found necessary to modify the diet to such an extent as to reduce the weight of the host before any effect upon parasitism could be shown. This laboratory conclusion appears to have been a hasty one, however; for inquiry into the agricultural conditions of the maintenance of stock reveals that the ordinary nutritional stresses incumbent upon the seasonal variation in growth and quality of herbage are very great indeed, and that the economic need for the sparse feeding of store animals often results in their being kept alive on a diet that is considerably below the requirements for full maintenance. Towards the end of a dry summer ewes and lambs may have great difficulty in finding sufficient food on the bare pastures; and, as a direct result of their low diet, hill sheep may actually lose one quarter of their weight during the winter months, while store cattle often pass the winter in a state of progressive emaciation. Taking the larger view, therefore, of grazing animals and their parasites under actual agricultural conditions, it must be concluded that, contrary to the opinions of laboratory epidemiologists, the influence of diet upon parasitism may be of very considerable importance.

The general trend of helminthological investigation may be said, therefore, to be in the direction of epidemiology, and to be proceeding through three channels: the effect of the hosts' environment on the parasites; the effects on the parasites of the development of immunity in a group of hosts; and, lastly, the effect of parasiticidal treatment. Trial and error methods of investigation still produce occasional successes in the revelation of new and better anthelminthic substances, so that great advances may be made in that direction, and greater still when at last the rationale of anthelminthic action is understood. Even in the sphere of treatment, however, the epidemiological trend may be seen, as for example in the recognition of the need for treatment to be applied to the whole group of animals, affected and unaffected individuals alike, and for finding (*a*) the most advantageous time of year at which to apply treatment, (*b*) the age of the group when treatment is most likely to give results, (*c*) the best use of treatment to assist the establishment of immunity in the group, and (*d*) the benefit to be derived from the treatment of groups of animals affected to only a slight degree, as in the recently recognized subclinical parasitic gastritis of sheep.

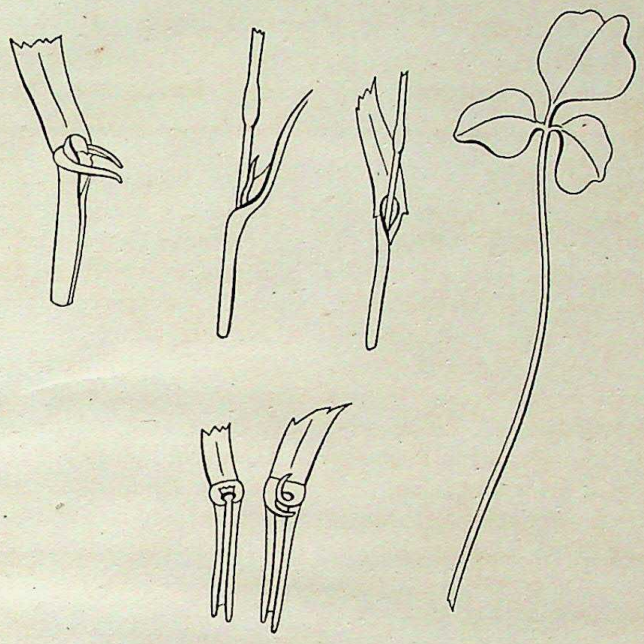

FIGURE 6 – *Junctions of blade and sheath of the leaf in different grasses showing the structure which prevents the ascent of strongyloid larvae. There is no obstacle to the ascent of the clover leaf and most of the larvae are found on the upper side of the trifoliate lamella.*

(The photographs were taken by Mr A. Norman of the Veterinary Laboratory, Ministry of Agriculture.)

The field for the immediate future will doubtless be that of chemotherapy. As yet, the modern methods of investigation have scarcely been applied to veterinary parasitology; but there is every reason to suppose that their employment, which is already beginning, will be rewarded by the same success that has been obtained in other branches of medicine. Our present knowledge of the parasites and of their association with disease will then enable us to use any new and effective parasiticidal drug to the best advantage, and help us to establish more satisfactory control than we are able to do at the present time.

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'Perspex': methyl methacrylate polymer

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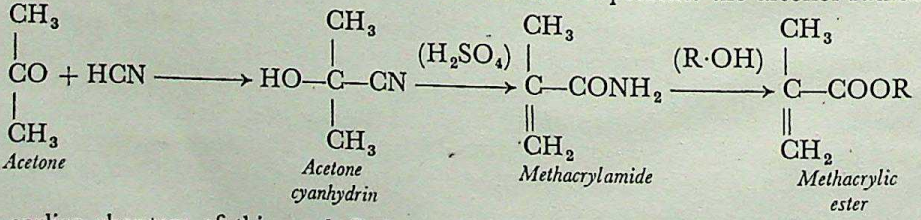
A. CARESS

Modern chemistry is supplying the world with entirely new products, which it would be inaccurate to regard as mere substitutes for older ones. Among the most useful of them is the solid transparent thermoplastic known as 'Perspex,' the chemistry and applications of which are described by Dr Caress in the following pages. A decade ago methyl methacrylate, the parent substance of 'Perspex,' was still a laboratory curiosity: today it has been transformed into an important industrial raw material and is manufactured on a large scale.

The names of organic compounds are dictated by scientific accuracy and convenience, and therefore cannot always be simple or pleasing. Much-used organic materials are thus often known by their trade names rather than by their chemical names. One of these is polymerized methyl methacrylate, which in the form of sheet and rod is well known as 'Perspex' in this country, as 'Lucite' in the United States, and as 'Plexiglas' in the United States and on the Continent. There is a tendency to use the word acrylic as a generic name, but there is no avoiding the longer chemical title of polymethyl methacrylate, if the substance is to be distinguished from the softer polymers obtained from esters of acrylic acid or the higher esters of methacrylic acid.

The first preparation of an acrylic monomer was reported by Frankland and Duppa in 1865 [6]. This was ethyl methacrylate, and its tendency to polymerize was noted by Fittig and Paul in 1877 [5]. Meanwhile Caspary and Tollens in 1873 [3] had described the preparation of some esters of acrylic acid, and the polymerization of methyl acrylate was reported by Kahlbaum in 1880 [9]. Systematic work in the acrylic field started early in the present century, when Röhm followed up his academic researches [10] by taking an active part in the industrial development of acrylic ester polymers in Germany.



During the earlier chapters of this work Röhm was interested mainly in softer products, for use in lacquers and safety glass or as rubber substitutes, though it is possible that methyl methacrylate polymer was examined by Röhm even if he did not realize the potentialities which lay in its greater toughness and hardness. Indeed, there is a passing reference to the polymerization of methyl methacrylate in a Swiss patent, filed by Röhm and Haas and published in England in 1931 [11]. About the same time Chalmers was granted a Canadian patent [4] claiming a method of polymerizing ethyl methacrylate.

Rowland Hill [7] of Imperial Chemical Industries was the first to study methyl methacrylate monomer and polymer in detail and to appreciate the possibilities; and from this point the technical development started. However, it was only after an economic process for synthesizing methyl methacrylate had been invented in Britain that large-scale production became feasible. The British synthesis which marks the beginning of the development of methyl methacrylate as an industrial chemical was discovered in the I.C.I. laboratories and was published in a patent in the name of Crawford [8]. This synthesis from acetone, hydrocyanic acid, sulphuric acid, and methanol was improved in succeeding years [1] and is the process used in large-scale manufacture both in this country and abroad. It is also applicable, by varying the alcohol, to certain other esters of methacrylic acid. The chemical reactions are summarized in the following equations, in which R represents the alcohol radical:

Methyl methacrylate is a liquid of specific gravity 0·95 freezing at $-48°$ C and boiling at 100° C. It has a characteristic and now familiar odour. It is safe to transport and store in the pure

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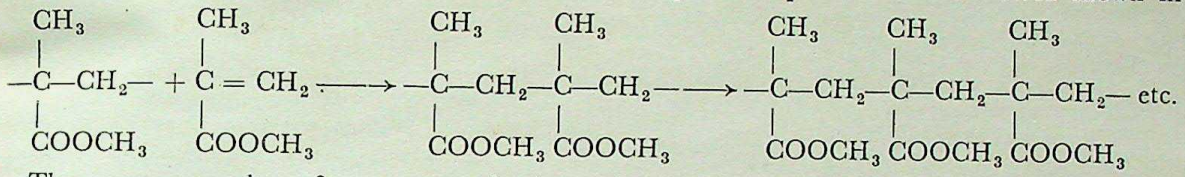
state, without the addition of polymerization inhibitors, so long as the temperature is not allowed to get too high. It can be polymerized to a rigid transparent solid by a variety of means, of which at least two have been developed industrially. These are the granular polymerization process [2] and the polymerization-casting process.

Polymerization occurs by activation of the monomer molecule, usually conceived as an opening of the double bond, followed by the rapid addition of unactivated monomer molecules to form long polymer chains:



The average number of monomer units in a polymer chain is 500–600 for granular polymers and 1,800–3,000 for cast polymers, though values outside these limits can be obtained. The chain lengths quoted are necessarily approximate, being based on Staudinger's specific viscosity method, which is not accurate for long-chain molecules even in very dilute solution. It is, however, the easiest method of estimating average chain length and is very useful as a control test. Specific viscosity is the difference in viscosity of a solution of polymer in solvent and that of the solvent, expressed as a fraction of the viscosity of the solvent itself. It is taken to be proportional to chain length and to the concentration of a sufficiently dilute solution. The constant of proportionality used in determining the limits for chain length quoted above is 0·00031 for a concentration of 1 gm per litre with chloroform as the solvent. Thus, specific viscosity = 0·00031 × number of monomer units in the polymer molecule for a solution of that concentration in chloroform.

The granular process results in a product in the form of perfect tiny spheres, illustrated in figure 1. They are the basis of clear and coloured powders, used for moulding and for the making of dentures.

The polymerization-casting process can be illustrated by the method of making the transparent sheet familiar as 'Perspex.' The monomer, with a trace of a catalyst such as an organic peroxide, is allowed to thicken and harden between glass plates in ovens at a moderate temperature, accurately controlled to a time schedule. Allowance has to be made, during polymerization, for removal of the heat of reaction and for the shrinkage of about 20 per cent. in volume which takes place. The shrinkage is constrained to occur in the thickness, and not in the area, of the sheet by means of compressible gaskets, chosen to give the desired thickness to the final solid sheets. The sheets, sandwiched between glass plates, are stripped by a special process from the glass, which is washed and dried mechanically and used again.

'Perspex' is a transparent, colourless thermoplastic of specific gravity 1·19. It is normally supplied in flat sheets up to $\frac{3}{8}$ in. thick and up to 54 in. × 48 in. in area, but larger sheets are made for special requirements. The block shown in figure 2 is a more striking illustration of the polymer in bulk. The commercial varieties usually contain a small percentage of a plasticizer, such as dibutyl phthalate, which is added to the monomer before polymerization. Its effect is to lower the softening temperature, and hence the temperature to which the sheet has to be heated (about 120° C) to enable it to be shaped into useful forms. There are, however, unplasticized varieties, including a special optical grade used in the manufacture of lenses and prisms, illustrated in figure 3. For the making of achromatic doublets, pure polystyrene is used as the 'flint' component, polymethacrylate corresponding to the 'crown.' A few of the physical properties of plasticized 'Perspex' and the two optical materials are shown in the table on page 158.

As might be expected from its molecular structure, with short polar side-chains, 'Perspex' has good mechanical properties. It is also a good electrical insulator, but it cannot, of course, compare in power factor with hydrocarbon polymers such as polythene and polystyrene. No short table of properties, however, can bring out that balance of chemical, mechanical, and optical properties which has made 'Perspex' pre-eminent among transparent plastics. It is tough enough to stand rough usage down to the lowest temperatures encountered by aircraft, without the brittleness of the inorganic glasses. In common with almost all plastics, it absorbs a small amount of water, but, unlike the majority, it is unaffected in appearance, dimensions, and physical properties by the absorbed moisture. The rate of diffusion of water vapour through 'Perspex' is even lower than through polystyrene. It is colourless and

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PHYSICAL PROPERTIES

Materials	Polymethyl Methacrylate		Polystyrene
	Plasticized ('Perspex')	Unplasticized ('Transpex' 1)	Unplasticized ('Transpex' 2)
Mechanical			
Specific gravity at 20° C	1·19	1·189	1·053
Tensile strength (lb./sq. in.):			
At 40° C	5,000	—	—
20° C	7,000–9,000	10,000–11,000	5,000–6,000
−60° C	14,000	—	—
Cross breaking strength (lb./sq. in.) at 20° C	12,000–16,000	16,000–17,000	10,000–12,000
Modulus of elasticity in bend (lb./sq. in.) at 20° C	450,000	480,000–520,000	450,000–500,000
Thermal			
Softening temperature (empirical test)	78° C	105° C	102° C
Coefficient of linear expansion per ° C	$97{\cdot}5 \times 10^{-6}$	80×10^{-6}	86×10^{-6}
Thermal conductivity (C.G.S. units)	$5{\cdot}0 \times 10^{-4}$	$3{\cdot}5 \times 10^{-4}$	$2{\cdot}0 \times 10^{-4}$
Optical			
Refractive index $\left(n_D^{20}\right)$	1·4949	1·4900	1·5900
Relative dispersion $\left(\frac{n_D-1}{n_F-n_C}\right)$	53·7	57·5	31·0
Reduction in intensity of visible light passing normally through sheet	8 per cent.	8 per cent.	10 per cent.
	(almost entirely due to reflection losses)		
Electrical			
Dielectric strength on $\frac{1}{8}$ in. thick specimen (volts/mil):			
Dry	390	—	500
After 24 hours in water	380	—	500
Permittivity:			
At 1 megacycle/sec.	2·8	—	2·3
3,000 megacycles/sec.	2·6	—	2·5
Power factor:			
At 1 megacycle/sec.	0·02	—	0·0006
3,000 megacycles/sec.	0·012	—	0·0005
Volume resistivity (ohm–cm.)	10^{15}	—	10^{17}

remains so after years of exposure to sun and rain. Consequently its possibilities as a vehicle for 'solid colour' are limited only by the availability of suitable light-fast dyes and pigments. It can be coloured throughout in opaque colours or in pastel tints.

'Perspex' has no effect on, and is itself unaffected by, a variety of corrosive inorganic compounds. It is, for example, unchanged by long periods of immersion in sea-water and exposure to dry or moist gases, such as sulphur dioxide, hydrogen sulphide, oxides of nitrogen, ozone, etc. Concentrated alkalis and mineral acids up to about 30 per cent. strength have no effect. Certain classes of organic solvents dissolve 'Perspex' completely, e.g. some aromatic hydrocarbons such as toluene, simple esters such as ethyl acetate, the lower ketones such as acetone, and chlorinated bodies such as chloroform and ethylene dichloride. Such solvents are used in making adhesives with which panels can be cemented together. Methyl methacrylate itself is among the best solvents for its own polymer. During the course of polymerization there is a continuous change from the limpid monomeric liquid through a 'syrup' of gradually increasing viscosity, which is a solution of polymer

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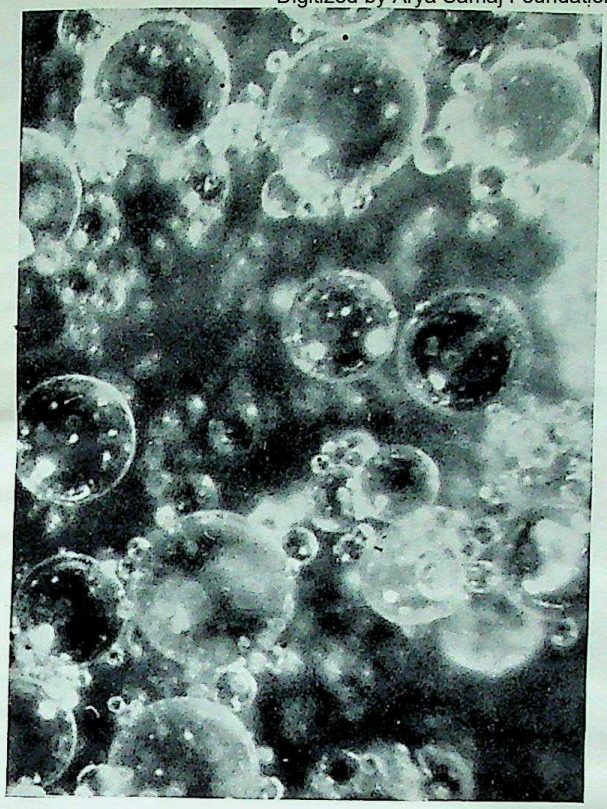

FIGURE 1 – *Photomicrograph* (× 100) *showing methyl methacrylate polymer in the form of hollow spheres as produced by the granular polymerization process.*

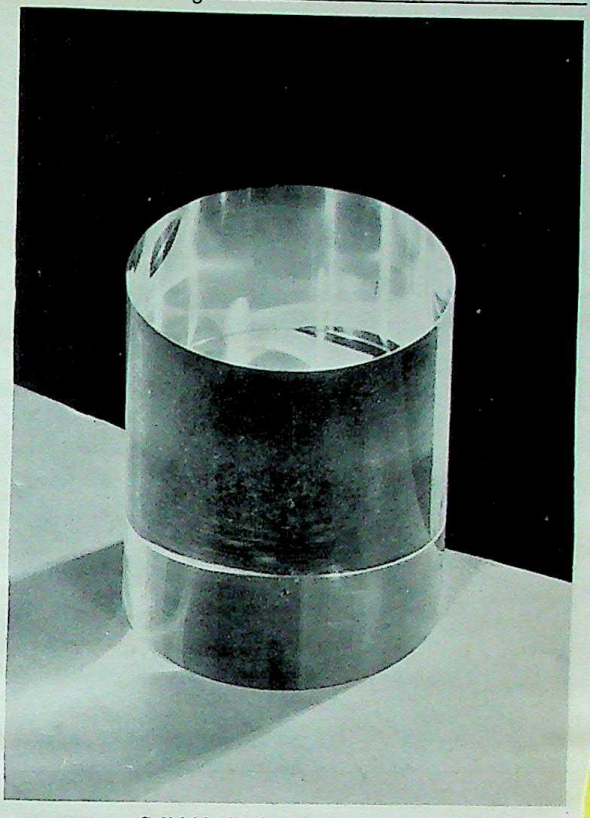

FIGURE 2 – *Solid block of cast methyl methacrylate polymer.*

in monomer, to a solid solution of monomer in polymer, and finally to polymer substantially free from monomer. Most organic compounds, other than those named, have little or no effect on 'Perspex.'

Research on the structure of methyl methacrylate polymers is hampered by their failure to form crystals, thus immobilizing the powerful weapon of X-ray analysis. This behaviour is no doubt associated with the chemical complexity of the monomer unit compared, for example, with ethylene, the progenitor of the general type $CH_2 = CR_1R_2$ to which methyl methacrylate, vinyl chloride, styrene, etc., belong. There is evidence from solubility studies that pure polymethyl methacrylate is made up of linear polymer chains with a fairly broad distribution of the number of monomer units per chain around the average number. Although cross-linking of the chains can be achieved by co-polymerizing with a small quantity of a monomer with two ethylenic double bonds—such as glycol di-methacrylate—the pure polymer is believed to be substantially devoid of branched or cross-connected chains.

FIGURE 3 – *Group of plastic lenses and prisms, including achromatic doublet of polymethyl methacrylate and polystyrene.*

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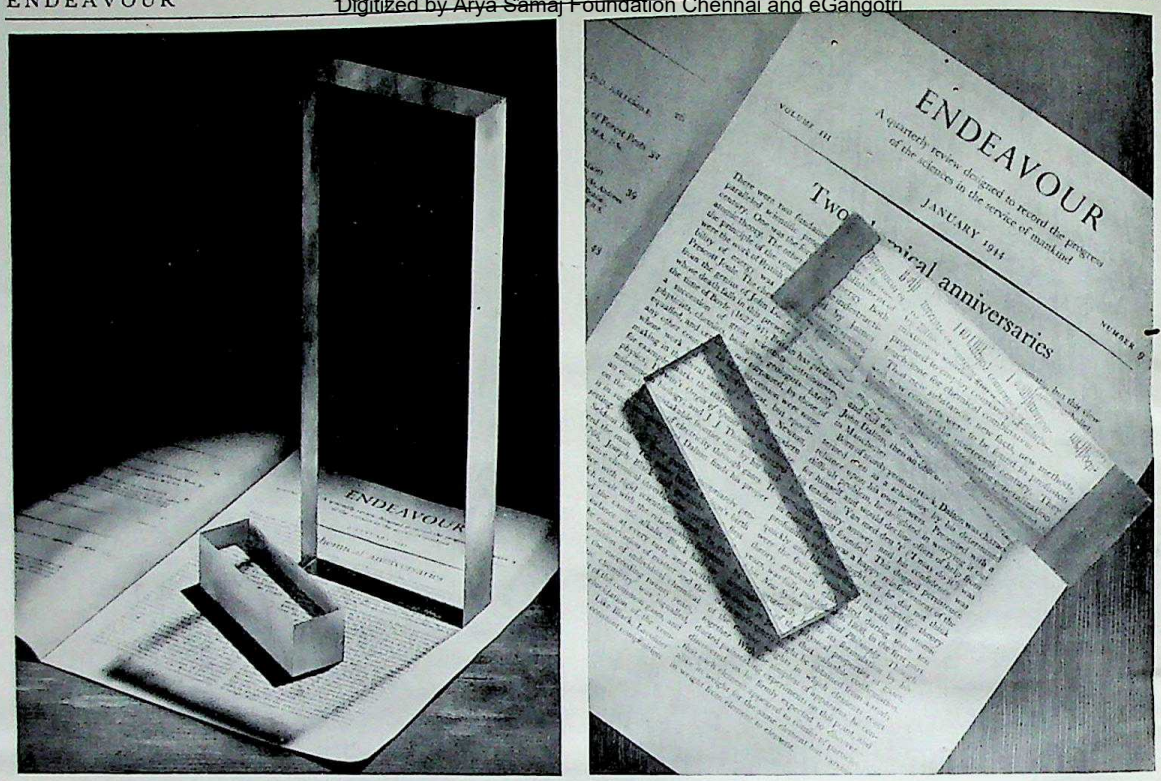

FIGURE 4 – *Photographs illustrating the remarkable transparency of 'Perspex.' The photograph on the left is a side view of blocks 1 in. and 1 ft. high resting on a page of print. The right-hand photograph shows the print taken downwards through the 'Perspex.'*

On pyrolysis at around 400° C, the polymer is 'depolymerized' rapidly to methyl methacrylate monomer in high yield, with only small quantities of by-products. The depolymerization of the plasticized polymer gives a crude product in lower yield, as it contains the products of decomposition of the plasticizers.

Heating the polymer at somewhat lower temperatures while subjecting it to mechanical friction, as, for example, between heated rolls, results in a lowering of average chain-length by breaking down the longer molecules. Examination of 'Perspex' before and after this treatment, by means of the ultracentrifuge, indicates that the lowering of average molecular weight is accompanied by a narrowing of molecular weight distribution. This deduction is supported by the observed fact that the heat-treated product has a sharper softening range than the untreated polymer—a fact of technical importance in the production of varieties for moulding by the injection process. The wide softening range distinguishes 'Perspex' from the highly crystalline polymers such as polythene, nylon, and polyvinylidene chloride, which have relatively sharp melting-points.

The lack of any tendency to crystallize facilitates the production of a polymer in an optically isotropic form, such as 'Transpex' 1. By attention to detail, three desirable properties can be combined. The material can be made optically homogeneous, highly transparent, and constant in refractive index from sheet to sheet. The deviation from optical homogeneity, as measured by the interferometer, can be made as little as, or less than, that of the finest inorganic optical glasses. The transparency to ordinary white light is such that the eye can scarcely detect the difference in looking through a fraction of an inch and several feet of the material (see figure 4). The refractive index can be kept constant to 0·0001 over a whole series of sheets—a result which cannot be reckoned on unless the starting material is a pure synthetic chemical. Unplasticized 'Perspex' is transparent to ultra-violet light down to 2,900 A, and the plasticized variety transmits down to 3,000 A.

Plastics have sometimes been limited in use by being regarded as substitutes, both before the war

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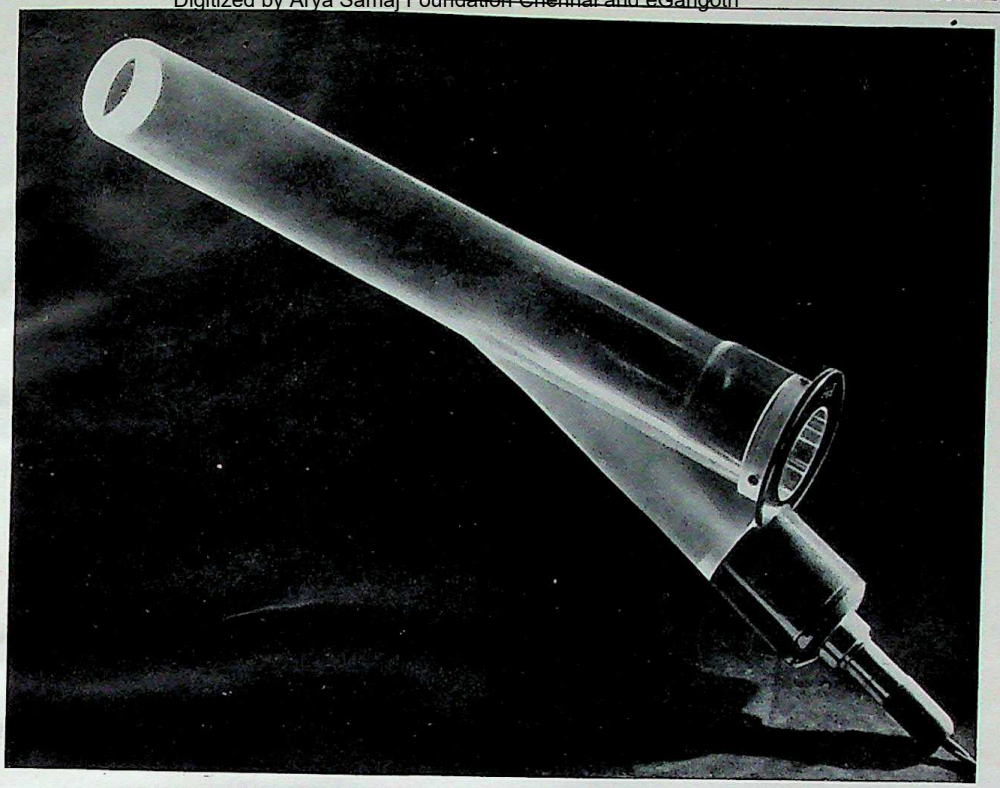
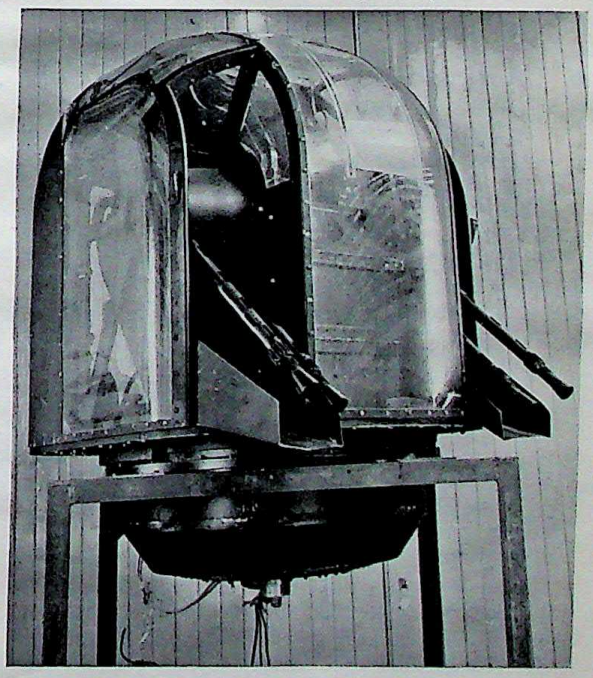


FIGURE 5 – *Photograph of a bovine vaginal speculum used in veterinary work. It has a light source at one end and the light is conveyed through the 'Perspex' tube wall to the other end, thus permitting internal inspection ('Coldlite' bovine vaginascope, British Patent* 551146).

when they were replacing wood, metals, and ceramics, and during the war, when they were called upon to make good the shortages of other materials. Although 'Perspex' is transparent, it is wrong to think of it as a substitute for glass. It has found its most important war application in those secondary structures on aircraft which must be seen through, such as the shaped roofs of pilots' cabins, gun-turrets, and observation domes (see figure 6).

The chief disadvantage of 'Perspex' as a transparent sheet material is that, like many other plastics, it lacks resistance to abrasion. Its perfect clarity allows every faint scratch to be seen in sharp relief when viewed at the correct angle, though when coloured in the bulk it does not show up scratches nearly so markedly. With the growth of experience in handling the material, troubles from this cause have not proved as serious in service as might have been expected, and superficial scratches acquired in service can be removed easily by polishing. Surface scratching might be a more serious defect in plastic optical components, since the polishing out of scratches,

FIGURE 6 – *Parnell turret made of 'Perspex.'*



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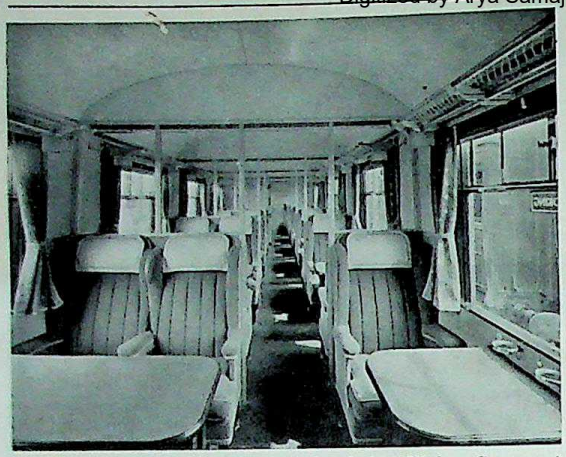

FIGURE 7 – *Interior photograph of the 'Flying Scotsman' showing the use of flat 'Perspex' panels separating the back-to-back seats all along a compartment.*

FIGURE 8 – *Motor coaches with curved 'Perspex' side lights.*

which is quite practicable for non-optical uses, would not be permissible for precision lenses and prisms. Fortunately it has been found that the usual care given to optical instruments is enough to protect the lenses and prisms from serious harm.

In the optical field plastics are no longer substitutes. For example, the production of aspherical lenses from inorganic glasses is prohibitive in cost for many instruments, since each lens has to be ground and polished individually; but with transparent plastics the contour can be repeated almost indefinitely from one accurate model.

A less important defect of 'Perspex,' also shared by many other plastics, is a high coefficient of expansion, which is 7 to 9 times that of steel and 10 to 12 times that of glass. Although troublesome, this can be allowed for by the use of suitable gaskets.

Use has been made of the high transparency of 'Perspex' in 'piping' light round bends. Light is led from one end of a bent rod or tube through the material to the other end, from which it emerges only slightly diminished in intensity. The curves and the light-source are arranged so that the light is totally internally reflected and kept inside the rod or tube until it reaches the desired point. Such devices are used by dentists for illuminating the interior of the mouth, and by surgeons for providing light at the seat of intricate operations. The method has also been applied successfully to veterinary operations, of which an interesting example is illustrated in figure 5. This is a vaginal speculum, the use of which has been described recently by Steele-Bodger [12]. Surgeons are also experimenting with 'Perspex' for a variety of uses, including artificial eyes, splints, supports, and cranial plates.

'Perspex' has already been used to a small extent in transportation other than in aircraft. The same shaping techniques have been used to make curved panels for motor-cars and speed-boats. Applications of flat sheet in railway vehicles and curved panels in road transport are illustrated in figures 7 and 8.

'Perspex' is also being introduced as a raw material for fabricating by hand, alongside wood and metal, in schools, training centres, and rehabilitation centres. Industrial artists are beginning to appreciate the intrinsic qualities of the material and to create new designs in harmony with those qualities.

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SCIENCE AND CIVILIZATION

The Impact and Value of Science, *by D. W. Hill. Pp.* 88. *Hutchinson's Scientific and Technical Publications, London.* 1944. 7*s.* 6*d. net.*

Books on this subject tend to resemble each other closely; but some of Dr Hill's opinions and proposals are out of the common, as the following quotations will show:

'Scientists, in their writings, are too truthful, and that makes them dull.'

'Science, in its passion for exactitude, is becoming increasingly mathematical and seemingly divorced from reality.'

(In the chapter on 'Science and Politics') 'There is, however, every reason to believe that a government of scientists might be a most truly democratic government.' 'Are we, then, to advocate a government of scientists? Why not?'

The author proposes that students who wish to become specialist teachers in secondary schools should not, as at present, take university honours in their subject, but should have instead a four years' course in a Faculty of Education. It may perhaps be felt that this is giving undue importance to what in medicine is called 'bedside manner'; and it may be questioned whether Dr Hill is devising the best way to secure what he so much desires in the specialist teachers of science, viz. the scientific habit of mind.

The account of the triumphs of science in industry, though brief, is excellent, and the book as a whole is interesting reading.

E. T. WHITTAKER

A PICTURE OF THE UNIVERSE

The Universe Around Us, *by Sir James Jeans. Pp.* $x + 297$, *with* 32 *plates. University Press, Cambridge. Fourth edition.* 1944. 15*s. net.*

To set out to describe within the compass of a book of moderate size what astronomy has to tell us about the universe in which we live is a task that is far from easy. Sir James Jeans succeeds in presenting a well-balanced account of the methods and results of modern astronomical research. A wide field is covered; a whole chapter, for instance, is devoted to modern atomic theory, because a knowledge of this is necessary in order to understand the processes that occur deep in the interior of a star, the source of stellar energy, and the course of evolution of a star. Physics, chemistry, and geology are all, in fact, called upon to assist in the interpretation of the results of observation.

The problems of cosmogony and evolution, to the solution of which Sir James Jeans has himself made important contributions, receive special attention. He is careful to emphasize that the picture is fragmentary and can claim no finality: 'we are not describing the mature convictions of a man so much as the first impressions of a new-born babe which is just opening its eyes.'

In preparing this fourth edition for press, an account is included of the principal advances in astronomy that have occurred in the decade since the third edition appeared, and the opportunity has been taken to make a thorough revision of the book, which has been largely rewritten.

The book is written with Sir James Jeans's usual clarity of style and facility of phrasing. Many striking illustrations and analogies are used to impress a point on the reader; thus, for instance: 'Each time the child throws its toy out of its baby-carriage, it disturbs the motion of every star in the universe.' The plates are numerous and well selected, whilst the printing is of the high standard that we expect from the Cambridge University Press. The book can be confidently recommended as one of the best expositions of the subject in simple language, and it should pass through many more editions.

H. SPENCER JONES

THEORY AND DESIGN OF WAVE-FILTERS

Wave-filters, *by L. C. Jackson. Pp. vii* + 107. *Methuen & Company Limited, London.* 1944. 4*s.* 6d. *net.*

Wave-filters are electrical networks that pass alternating currents whose frequencies lie within a selected range and suppress or attenuate those of all other frequencies. They are an essential feature of almost every development of telecommunication. The student of physics or radio, to whom a knowledge of them is becoming increasingly important, has hitherto had to pick out certain chapters or sections from the large and highly technical standard works on electricity, radio, or telecommunication engineering, where he has found (often after a long search) the available information to be too elementary or too condensed for his needs or, in some cases, a compilation of design formulae and diagrams.

This monograph, a notable addition to an important and well-known series, will do much to remove his difficulties. It provides a readable and concise account of electrical wave-filters of various types, with enough of the underlying theory to enable the reader to use the many detailed formulae employed in their production, and to read profitably the larger works describing at greater length the technical details and practical applications. As a guide to further reading a bibliography of important books and original papers is provided. The application of the theory of wave-filters to mechanical and acoustical oscillatory systems is briefly described; this is a particularly good example of the interaction of advances in various branches of physics.

The text includes 64 well-prepared figures, mostly circuit diagrams and graphs, and is adequately indexed.

W. JEVONS

OUTLINES OF ORGANIC CHEMISTRY

Principles of Organic Chemistry, *by Sylvanus J. Smith. Pp. viii* + 569. *Macmillan & Company, Limited, London.* 1944. 15*s. net.*

This three-year course deals first with molecular formulae, physical properties, valency of carbon, classification, isomerism, and stereo-isomerism, before passing on to the systematic survey of aliphatic, aromatic, heterocyclic, and homocyclic compounds which constitutes the bulk of the book. In teaching practice, some of the initial topics could scarcely be handled before a single organic compound had been considered. Unusually, the book opens without a definition of organic chemistry. In a somewhat rigid treatment, the author takes into account the modern conceptions of valency and reactivity and gives a sound and competent factual presentation of the subject; but it should be mentioned that all historical background is lacking and that as a rule no particular attention is paid to industrial, economic, or biochemical aspects. There are numerous

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figures and diagrams, and the text and formulae are well printed. The text is not free from errors: the statement that 'Wohler' discovered 'the most important synthesis of urea' (p. 217) is inexact; 'the relation of object and mirror image' is not characteristic of optical antipodes unless object and image are distinct (p. 249); sodium ammonium racemate is not the sodium salt of racemic tartaric acid (p. 249); *d*- and *l*-carvone occur in oils of caraway and spearmint, respectively, rather than in those of 'carroway' and 'mint' (p. 509); and it is not usual to represent terpin hydrate as an open-chain compound (pp. 510, 512).

JOHN READ

WATER ANALYSIS

The Chemical Analysis of Waters, Boiler- and Feed-waters, Sewage, and Effluents, *by Denis Dickinson. Pp. xii* + 140. *Blackie & Son Limited, London.* 1944. 6*s. net.*

In this little book the important determinations in the chemical analysis of waters, sewage, and effluents are concisely described, but little guidance is given in the interpretation of results. Reliable methods have been well chosen, and it is a practical, up-to-date bench-book which will prove useful in laboratories undertaking water and sewage analyses. In preparing another edition, which will certainly be demanded, the author should mention the modifications of Hatfield's method for the determination of aluminium, described in *The Analyst*, 1943, **68**. There might also be included a sensitive method, such as Denigès' (modified), for phosphates in potable waters, and a method for the determination of phenoloids. In the determination of calcium in potable waters N/25 or N/80 permanganate would be preferable to N/8, and electrical conductivity, being concerned with total solids, could properly be included in chapter II instead of chapter XIII. Warning should be given that the diluting water used in B.O.D. determinations must be free from antiseptics such as chlorine and copper. Such statements as 'It is rather unusual for a natural water . . . to have no colour,' and '500 ml. of a good quality water . . . should be evaporated to dryness' (in the determination of total solids) require modification.

E. V. SUCKLING

FUNGI: TO EAT OR NOT TO EAT?

Edible Fungi, *by John Ramsbottom. Pp. ii* + 35, *with* 16 *coloured plates. Penguin Books Limited, Harmondsworth and New York.* 1944. 2*s. net.*

This handsome little volume appears at an opportune time, for efforts have been made during the war to popularize the eating of certain kinds of wild fungi in this country as a means of adding variety to a somewhat monotonous diet. Before the war only the mushroom was commonly eaten in Britain, unlike the custom in other European countries. By lectures and exhibits at the Natural History Museum, London, and in other ways, the author of this book has done much to teach the public that many other kinds of fungi are at least as wholesome and delicate in flavour as the mushroom. In this 'King Penguin' Dr Ramsbottom describes twenty common edible species in interesting detail, and illustrates them by such excellent coloured drawings by Rose Ellenby that no mistake can be made in identification. Correct determination is important because many toadstools are unwholesome and a few are really poisonous. Recipes for cooking are given, but epicures will probably long for the time when more adequate supplies of butter are available. The Morel, Blewits, Chanterelle, Fairy Ring Champignon, Beefsteak Fungus, and Giant Puff-ball are among the species described, but the subterranean Truffles are omitted, doubtless owing to their extreme rarity in Britain except in a few favoured localities.

F. T. BROOKS

PRINCIPLES AND APPLICATIONS OF GEOLOGY

Geology in the Service of Man, *by W. G. Fearnsides and O. M. B. Bulman. Pp.* 158, *with* 8 *plates. (A Pelican Book.) Penguin Books Limited, Harmondsworth and New York.* 1944. 9*d. net.*

The appearance of a Pelican Book on geology is to be welcomed, for too little has been done in recent years to interest the lay reader in this science, which is so fundamental to an understanding of many problems, and yet is sadly neglected in British educational curricula. The title would perhaps imply that this book deals only with the applications of geology, but the authors have adopted a wider interpretation, and the first half of the book is essentially a general introduction to the principles of geology. This part, on 'The Nature of the Evidence,' includes chapters on the crust of the earth, the building of continents, the development of scenery, an epitome of the geological history of Britain, and the construction of geological maps. To cover these topics in about 25,000 words has naturally involved much condensation, and some portions will be heavy reading for those with little knowledge of physics and chemistry. Within these limitations, however, the authors have performed their task admirably, and although the book is packed with information the writing is clear and stimulating.

The second half of the book deals with 'Some Applications of Geology,' and there are sections on water supply, soils, oil, engineering geology, mineral supplies for heavy industries, non-ferrous metal supplies, and gemstones. These chapters are necessarily short, but they give a clear indication of the importance of geological data in many problems. It may be hoped that this publication will extend among engineers and scientific workers an appreciation of the usefulness of the science. There are numerous clear text illustrations, and eight plates, with suggestions for further reading and a useful index. It is to be regretted that the volume is not available in a more permanent form.

A. E. TRUEMAN

METAL FINISHING BY RADIANT HEAT

The Application of Radiant Heat to Metal Finishing, *by J. H. Nelson and R. Silman. Pp. vi* + 79, *with* 37 *figures. Chapman & Hall Limited, London.* 1944. 8*s.* 6*d. net.*

This is a timely publication dealing with an industrial process which is already being widely used and which has a special application to mass-production. In writing the book, the authors have very wisely assumed that the use of the process should be accompanied by some knowledge of the physical principles involved in it, and for this reason the chapters on heat transference and paint formulation are particularly welcome. The types of plant already in use are described and illustrated, but it is made abundantly clear that, in introducing the process, careful consideration must be given to the particular design most suitable for each specific purpose.

A. J. PHILPOT

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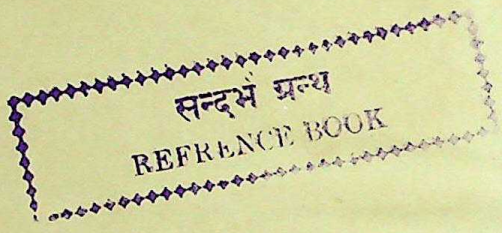

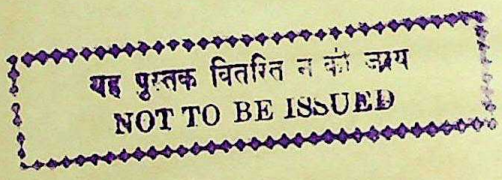

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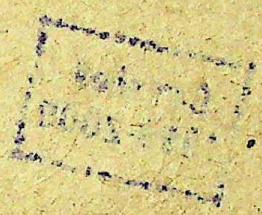

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